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SEMICONDUCTORS AND THE TRANSISTOR *

BY

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INTRODUCTION

The transistor has made many scientists in unrelated fields aware of the importance of a class of materials known for many years to the physicist. These substances, known as semiconductors, have electrical resistance mid-way between insulators and metals, and this fact alone provides the only workable definition. Metals have their electrical resistivity expressed in microhm-cms., that is, millionths of an ohm-cm., while good insulators have their resistivity expressed in millions of megohm-cms. This range of 10^{-6} to 10^{+12}, or 18 orders of magnitude, encompasses a wide variety of possibilities, of which the range of 10^{-3} to 10^{+6} ohm-cms. is perhaps of greatest practical interest for semiconduction.

What is the predominant factor which makes the semiconductor of such interest today? Modern technology is based on control of much by little, control of many by few; in electronics, this is called "amplification" or the ability of a small input to control a large output. The electron tube was, perhaps, the first major advance and the transistor appears to be the second. In the tube, one controls free electric charge carriers in a vacuum or rarefied gas, in the transistor these electric charges stay inside a solid material. But again, why does one need the semiconductor? This is quite simple, really, since, in a metal, the free charges which carry electric current are much too plentiful to be readily controlled by a low power. In an insulator, the free charges may not normally be present and so, again, control is difficult. Only in the semiconductor is the number of free charges neither too great, nor too

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few, and one is able to build an "amplifier." Interestingly enough, the solid-state photodevice utilizes approximately the same resistance range, so that photoconduction and semiconduction are but two aspects of an essentially similar class of materials.

In the present discussion, the main emphasis will be on the transistor, with relatively little review of the older and simpler devices such as the diode rectifier or the photodevice. For background, a short historical survey will be given outlining some of the milestones on the way. Then the basic principles of semiconduction will be discussed. The techniques, with which the two currently important elements, germanium and silicon are applied to the diode and the transistor, will also be reviewed. The discussion closes with a description of present commercial and laboratory developments and some views into the future of this new art.

HISTORY

Historical background can be divided into two aspects, the first concerned with actual experimental devices, and the second about man's understanding of these devices.

The beginning of the modern semiconductor device came in the early 1870's when Ferdinand Braun (**1**)[2] observed electrical nonlinearity, that is, rectifying action, in certain metallic sulphides such as galena and pyrites. At about the same time selenium became of interest and, by 1883, Fritts devised a selenium rectifier which already had modern features (**2**). The advent of wireless telegraphy, or radio as it is now called, led to an extensive exploration of the sulphides and many other natural minerals as radio detectors (**3**). The first recognition that the element, silicon, could be used was due to Pickard (**4**), about 1906. As early as 1911, Merritt (**5**) used silicon as a detector of radio waves at the (then) phenomenally short wavelength of 15 cm. (2000 megacycles per second). Today, the silicon crystal detector still reigns supreme for use at the highest frequencies, called microwaves, and has been used up to 60,000 megacycles and higher.

The 1920's saw a very wide use of the crystal detector in early broadcast reception, and it is rare to find anyone over 40 today who does not remember the experience of searching for a sensitive spot with a "catwhisker" on a piece of galena. About 1926, another element, germanium, was added to the list of useful rectifying materials (**6**). This same decade saw not only the announcement of the large-area copper oxide rectifier (**7**) but the first real appreciation of the role the semiconductor could play in the more significant area of amplification, with the filing of some patents by Lilienfeld (**8**). The 1934 patent application of O. Heil (**9**), however, shows the first glimpse of a semiconductor triode amplifier device which can be said to be modern in concept.

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

Unfortunately, the techniques available in the 1920's and 1930's were still inadequate to support the ideas which were advanced. The only published record of any experimental results on a solid-state amplifier was the Hilsch and Pohl potassium-bromide crystal amplifier of 1938; this used ionic phenomena and was too slow in action for practical application (10).

Coming now to the World War II period, the silicon crystal, in improved form, made possible microwave radar, and interest in the relatively unexplored semiconductor element, germanium, was revived. Simultaneously in Germany and in the U. S. germanium was investigated and its importance became established by Benzer's discovery (11) of the high-back-voltage point-contact rectifier, which overcame the low-voltage limitations of earlier crystals. This war period was significant also in the abandonment of natural minerals for detector devices, substituting controlled synthesis and purification of the two most suited elements, germanium and silicon (12).

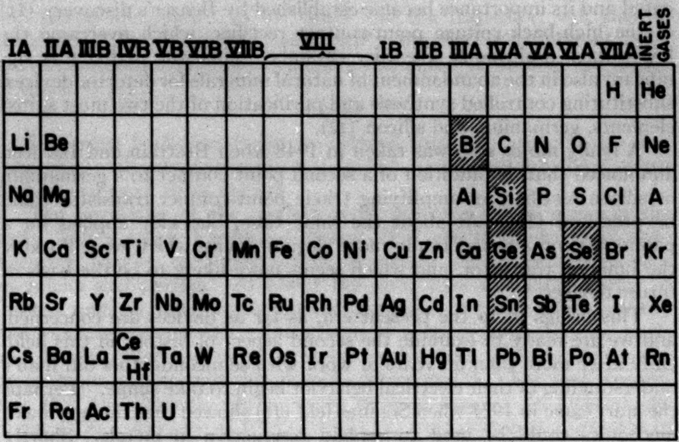
A really major step was taken in 1948 when Brattain and Bardeen announced that, by addition of a second point contact to a germanium or silicon rectifier, an amplifying triode point-contact transistor could be produced (13). At about the same time, Shockley applied for a patent (14) on a conceptually more elegant device which we call today the junction transistor, and which seems more likely to be the basis of future devices.

This brings us to the present era, as far as devices are concerned, and we are ready to examine the second aspect of history in this field. Only after more than 50 years of work with semiconductors did man's understanding of their electrical behavior begin to take shape. Perhaps the start came in 1928 when Sommerfeld (15) showed that the new wave mechanics could be used to explain conduction in metals. Shortly thereafter, another German physicist, Gudden (16), recognized that the conduction in semiconductors was almost entirely due to the impurities in them, rather than to their intrinsic properties. This, of course, was highly significant but became much more so in 1931 with Wilson's work establishing the modern "hole" and electron concepts of semiconduction (17). Less than ten years later, the first theoretical pictures of rectification were published, for the semiconductor-to-semiconductor junction (now known as a *p-n* junction) by Davydov (18), and for the metal-to-semiconductor junction by Schottky (19). The war period of 1939–1945 led to many advances but little publication, and it is difficult to pick out the important milestones. The monumental theoretical studies by Shockley and his colleagues (20), in the post-war period, may be said to complete the background for the rectifier and transistor, as we know it today.

It is now appropriate to discuss the present status of the semiconductor, and how it is used to make a rectifier or transistor.

SEMICONDUCTORS

The modern "band" theory gives acceptable explanations for most observed characteristics of semiconductors. In an insulator, there is a large "forbidden" band between the energy levels occupied by the electrons of the atoms and the next possible band, so the electrons are not free to move. In metals, there is no such band, while in semiconductors the band is intermediate, that is, it ranges from 0.1 electron volt to perhaps 3 volts for different materials. In a pure semiconductor, the only conductivity is due to electrons and holes produced by thermal energy. Greater conductivity can be provided by addition of impurities which may be of either electron-giving, that is, donor type, such as P, As, Sb, Bi, etc., or electron-collecting, that is, acceptor type, such as Ga, In, B, etc. For transistors, no use is made of the thermally-produced conduction and, indeed, it is not at all desirable because it varies so much with temperature. Instead, *n*-type and *p*-type semiconductors are used, whose conductivity is due to impurities of donor or acceptor type, respectively.



IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	INERT GASES
																H	He
Li	Be											▨ B	C	N	O	F	Ne
Na	Mg											Al	▨ Si	P	S	Cl	A
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	▨ Ge	As	▨ Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	▨ Sn	Sb	▨ Te	I	Xe
Cs	Ba	La	Ce Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Th	U													

FIG. 1. The shaded elements of the periodic table are semiconductors. Of great interest today are Ge, Si and many two-element combinations in and near column IVA such as GaAs, InP, CdS and Ge + Si.

Of great interest for transistors are two properties of a semiconductor.

1. The band gap, which is a measure of how much intrinsic (undesired) conduction is present. A large band gap is desired.
2. The electron and hole mobilities, which are a measure of how fast these charge carriers move in an electric field. A high mobility is desired.

Unfortunately, nature seems to have provided a relationship between band gap and mobility in many known semiconductors so that when one goes up, the other goes down. Mankind is presently trying to overcome this by a search for new materials. The problem is made more difficult in that maximum mobility can be achieved only in nearly-perfect crystals.

Examination of the periodic table, Fig. 1, is of interest. Only a small number of elements are available as crystalline semiconductors useful for transistors. For example, in Column IV, as we go up from tin to germanium to silicon to diamond, we have higher melting points and larger band gaps but smaller mobilities. Tin is too close to a metal and diamond is too close to an insulator. This leaves us only germanium and silicon for the transistor. There are certain borderline elements such as boron, selenium, tellurium, etc., which are potentially semiconductors but these are either not readily available in crystalline form or do not have suitable band gaps.

Among the mixtures and compounds, there is an infinite variety but none has been made in pure enough, or perfect enough form, so that its ultimate properties as a semiconductor are known. For the future, certain ones are of particular interest. First, we have the Column IV combinations, silicon carbide, germanium and carbon, and germanium and silicon. Each may be expected to have intermediate properties between its constituents and so lend greater variety to the simple valence crystals. Then we have the less homopolar crystals from Column III combined with Column V. One reads in the literature (21) about indium antimonide, gallium arsenide, indium phosphide and aluminum antimonide; perhaps one of these will provide a higher value of mobility for a given band gap. One also hears much about the Column II-Column VI combinations, cadmium sulphide, cadmium telluride, zinc selenide, etc. Finally, there are the traditional crystal detector compounds, the sulphides of lead, molybdenum, iron, etc. We must reserve judgment on all these compounds until they have achieved a higher state of development.

For the present, we are left with germanium and silicon as of greatest importance. It is of interest to compare their characteristics as shown in Table I. The effect of the larger band gap of silicon in increasing its intrinsic (pure) resistance at room temperature is clearly indicated. It

TABLE I.—*Properties of Germanium and Silicon.*

	Band Gap, electron volts	Resistivity ohm-cm.		Mobility cm^2./volt-sec.		Max. Temp., °C.
		Intrins. (Pure)	Useful (Impure)	Hole	Electron	
Ge	0.72	60	.1–10	1700	3700	100
Si	1.12	10,000	.1–10	300	1200	250

is because of this that silicon is useful to a much higher temperature than germanium. Unfortunately, one sacrifices something in mobility, so that silicon devices will not ordinarily have quite as good performance as germanium ones, when the latter are kept low in temperature. For this reason, it is likely that germanium will remain the most widely used substance for some time to come, though silicon may supplant it in special applications.

MODERN TECHNIQUES

Germanium and silicon are first purified chemically, and then by a zone melting process (22). When this stage is reached, there are no conventional means for measuring the impurity content, because it is so small. Instead, an indirect measure is used, the resistivity, using a curve as shown in Fig. 2, taken from a calculation by Herkart and Kurshan (23). Ordinarily we can reach about 40 ohm centimeters, which corresponds to one part impurity for each billion atoms of germanium. This is about ten or more times purer than necessary for transistors or rectifiers, which use resistivities between 0.1 and 10 ohm centimeters.

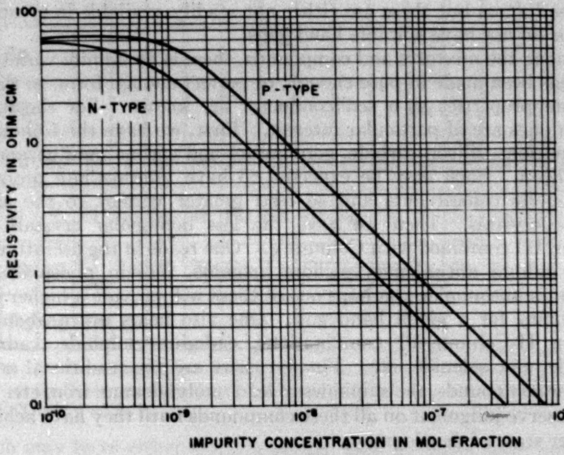


FIG. 2. Theoretical resistivity of germanium at room temperature as a function of impurity content. Such curves are often used to estimate purity.

For transistor or rectifier use, minute quantities of the appropriate *n* or *p* type impurities are added to a silicon or germanium melt and a single crystal is grown by the Czochralski technique (24). With this method, a cold seed crystal touches the melt and, as crystallization starts, the seed is slowly withdrawn (at about 1 mm. per minute) pulling with it a single-crystal bar of germanium or silicon. The perfection of the crystals of germanium grown in this way can be truly amazing. Although impurities may be present of the order of a part in 10^8, these are substitutional and not a major disturbance to the crystal. Based on charge carrier recombination data, it is believed that the major crystal defects, dislocations, etc., can be less than one for each 10^{11} parent atoms, and the crystals are as nearly perfect as any known to man.

The modern rectifier or transistor is based on using such crystals in electrically rectifying junctions, that is, contacts which pass current in one direction but not in the other. Such junctions can be metal-to-semiconductor, such as a point contact or a plated metal contact, or they can be a junction of two regions in a single crystal, which we call a *p-n* junction. Because of the importance of the rectifying junction, it is well to understand it. In Fig. 3(*a*) is shown a piece of single-crystal semiconductor which is electron-conducting (*n*-type) to the left of a central line, and hole-conducting (*p*-type) to the right. If the impurities are such as to produce about one ohm-centimeters resistivity on each side, one may schematically represent the charges as shown, in nearly equal numbers. When a battery is connected so as to make the right-hand terminal positive, holes and electrons both move in opposite directions across the central line and a heavy current flows (forward direction). The reversal of the battery leads to slight hole motion and electron motion *away* from the central line, so that almost no current flows (reverse direction).

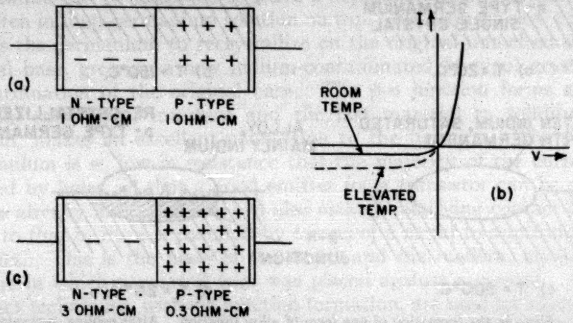


FIG. 3. The rectifying action in a *p-n* junction; (*a*) a junction of equal resistivity parts; (*b*) a junction of unequal resistivity parts with most current carried by holes; (*c*) rectifying characteristic of either type.

In Fig. 3(*b*) is the rectifying volt-ampere characteristic of such a junction. It is noted that some current does flow in the reverse direction. This is due to the thermally generated holes and electrons throughout the crystal, and these increase with temperature. For germanium, the currents are appreciable, but for silicon the reverse currents are so small as to be negligible at ordinary temperatures.

Junctions can be formed of many combinations, however. In Fig. 3(*a*) the forward current is carried by holes and electrons in almost equal quantity. In Fig. 3(*c*), the *n*-type portion has reduced impurity content (higher resistance, fewer electrons) while the reverse is true for the *p*-type. As a *rectifier*, the Fig. 3(*c*) device is just like the Fig. 3(*a*) device. But now the current is carried almost entirely by holes. In a *transistor*, one controls current carriers of only one sign, so that the so-called "emitter" of a transistor is designed to resemble Fig. 3(*c*) rather than Fig. 3(*a*), except that the ratio of resistivities may be even greater. Of course, the *n*-type and *p*-type roles may be interchanged and transistors can use either predominantly hole current, or predominantly electron current.

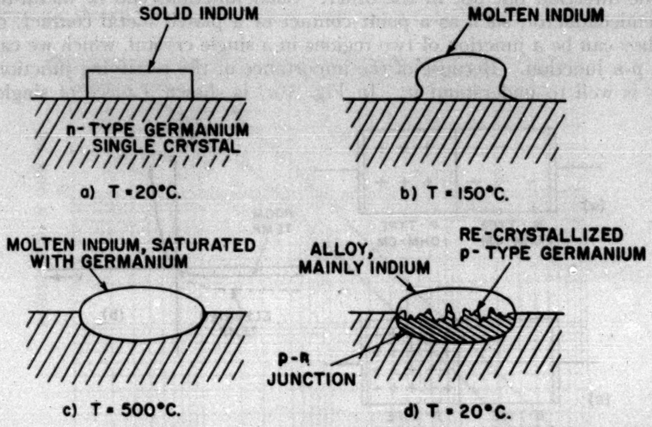

SOLID INDIUM
MOLTEN INDIUM
n-TYPE GERMANIUM SINGLE CRYSTAL
a) T = 20°C.
b) T = 150°C.
MOLTEN INDIUM, SATURATED WITH GERMANIUM
ALLOY, MAINLY INDIUM
RE-CRYSTALLIZED p-TYPE GERMANIUM
p-n JUNCTION
c) T = 500°C.
d) T = 20°C.

FIG. 4. Steps in the formation of one form of alloy junction. After cooling, recrystallized *p*-type germanium forms a junction at the original solid-liquid interface.

It is now appropriate to consider how rectifying junctions can be made in practice. If, during pulling a single crystal, an opposite type impurity is added to the melt, a *p-n* junction is formed; a double junction, *p-n-p*, or *n-p-n* can also be made. Alternatively, if the melt contains both *p*- and *n*-type impurities which have a different tendency to segregate between solid and liquid, one can change the growth rate suddenly, and obtain a reversal of impurity. Junctions made by either of these techniques are known as *grown* junctions and transistors made from such double junctions are *grown junction* transistors (**25**).

Another method of forming a junction is by diffusion in the solid state (**26**). An impurity is evaporated or plated on the surface of a crystal already containing an opposite impurity. Heating over a period of time causes the surface impurity to diffuse inward, producing a junction.

A commonly used method of producing a junction, however, is by a still different process called fusing or alloying (**27**). To illustrate the method, let us assume uniform *n*-type germanium, with a junction to be made by means of a *p*-type impurity such as indium. The steps are shown in Fig. 4(*a*) to 4(*d*). In Fig. 4(*a*) a small piece of indium is placed on the germanium. The temperature is raised just above the melting point of the indium as in Fig. 4(*b*). Germanium is slightly soluble in liquid indium, the solubility rising as the temperature goes up. By raising the temperature to about 500° C., as in Fig. 4(*c*), enough germanium can be dissolved to leave a depression in the surface, with a molten indium-germanium solution on top. Subsequent slow cooling causes the germanium to recrystallize on the original unmelted single-crystal base, growing a new indium-contaminated (*p*-type) crystal as a continuation of the original base. The *p-n* junction forms at the original solid-liquid interface and the last material to solidify, the indium, makes an excellent connection to the junction. The *p*-type germanium is so low in resistance that the majority of the current is carried by holes, so that a good emitter for a transistor can be made.

As already indicated, one can also make a rectifying contact analogous to that of the *p-n* junction by means of a metal-to-semiconductor contact. This is the basis of the early, and the modern, crystal detectors in which a pointed wire was placed against a crystal. Point-contact techniques, without junction formation, are used for transistors as well. However, one does not usually obtain current flow due to a single polarity of charge to as high a degree as with actual *p-n* junction formation.

Plated metal contacts can also be used to obtain rectifying and transistor action but they share with the point contact some disadvantage with respect to single-polarity charge flow in the forward direction. With a recently described technique, using liquid jets to electrolytically etch and then (by reversal of battery polarity) to plate on the same area, transistors have been made with fair success (**28**).

Protection of finished transistors and diodes is a matter of great importance. As a result of experience to date, neither hermetic seals nor moisture-resistant plastic cases are a sufficient criterion for complete stability. Both can, however, be satisfactory and both are being used. Nevertheless, the method of encapsulation, and the treatment of the exposed semiconductor surfaces prior to encapsulation, are critical manufacturing factors which are not yet completely understood. For this reason, variability during life remains a problem on some transistor types.

PRESENT COMMERCIAL DEVICES

Today, there are already a substantial number of commercial devices using semiconductors. We have had selenium and copper oxide rectifiers for many years and these will not be mentioned further. Similarly, the thermistor, which consists of a small piece of semiconductor with two electrical leads, has been available for many years and is used in many ways as an electrical indicator of a temperature variation. Since World War II, the largest production of a semiconductor device has been the simple crystal diode, that is, the low-power rectifier consisting of a "catwhisker" against a piece of germanium. The construction of such a diode is illustrated in Fig. 5. These have been made by the millions both in the U.S.A. and in Europe. Somewhat more recently, other diodes have been introduced commercially in the form of small selenium cells and, perhaps more important, junction rectifier devices using germanium and silicon. The silicon diodes, made with junctions, have an extremely low reverse current compared with germanium diodes and this current does not increase to excessive values when the operating temperature is raised. Such units should have wide usefulness in switching applications where complete isolation is desired between the two terminals in the cutoff condition. Germanium junction diodes have been made with sufficient cooling to withstand large amounts of power. In electrical performance, these power rectifiers are greatly superior to the selenium and copper oxide units hitherto obtain-

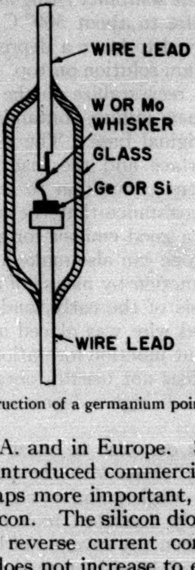


FIG. 5. Construction of a germanium point-contact diode.

able. They have yet, however, to prove themselves from the point of view of long-time reliability.

Turning to the transistor, the early forms were of the point-contact variety. The general construction of a point-contact transistor is shown in Fig. 6. Two point contacts are placed on the surface of a piece of germanium and it is found that the electrical current between one of these point contacts (collector) and the base of germanium is varied by the electrical current which flows into the second point contact (emitter). Best transistor action with point contact transistors is not achieved without the introduction during manufacture of a mysterious electrical process called "forming." In the process, an excess of current is passed through the collector contact to the *n*-type germanium. After this has been done, transistor action is greatly enhanced. Point-contact trans-

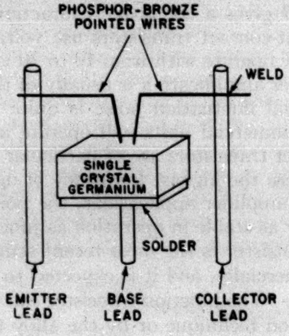


FIG. 6. Construction of a point-contact transistor.

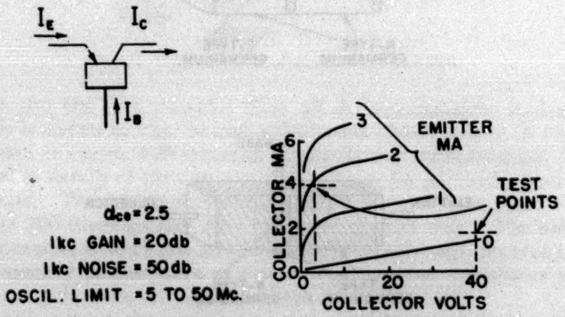


FIG. 7. Composite characteristics of commercially available point-contact transistors.

istors vary in their characteristics when surface conditions of the germanium are altered and also have variations when point-contact pressures and positions are changed. The theory of the forming process is sufficiently obscure so that art, rather than science, must be used to make a practical device.

There are a number of commercial types of point-contact transistor available and Fig. 7 gives a composite characteristic. In contrast to electron tubes, point-contact transistors use voltages about one tenth as high, that is, they operate with from 10 to 20 volts, usually at a few milliamperes. Power amplification is usually of the order of 100 times (20 db), and residual fluctuation noise is quite high compared with electron tubes. Commercial units will operate as high as 50 Mc. or more. Point-contact transistors are of particular usefulness in switching circuits and where the highest frequency of operation is necessary. For many ordinary amplifier applications, the point-contact transistor is not as reliable nor as stable in operation as junction transistors.

The junction transistor is the most recent semiconductor device to be introduced commercially, and it is expected to have a great impact on the electronic art. The junction transistor can be constructed either by the grown junction technique or by the alloy technique. Figure 8 shows how a grown junction is constructed by cutting off a bar of single crystal germanium which had the impurity content changed during growth. The other construction method, Fig. 9, uses two of the alloy junctions on each side of a wafer, as also shown in the figure. One can

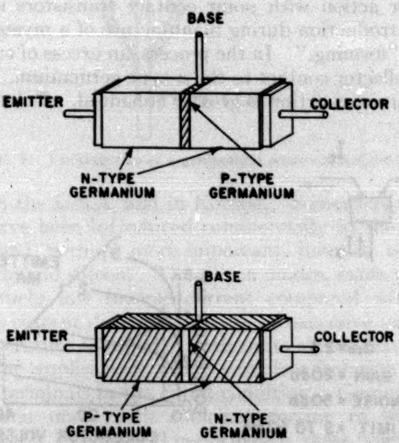


Fig. 8. Construction of grown junction transistors

make either a *p-n-p* type of transistor or an *n-p-n* type of transistor. These two types differ in that the one makes use of hole conduction and the other makes use of electron conduction. One uses a battery with a negative potential on the crystal, the other uses a battery with a positive potential. The two polarities of the transistor, therefore, complement one another and can be used in very interesting and novel circuits not available for electron tubes which have only one polarity. The junction transistor, as with the point-contact transistor, has three leads. The current to be controlled comes in one lead (emitter) and goes out a second lead (collector) and is controlled by the voltage or current which is impressed on the third lead, the base. Since the entire unit is a single piece of crystalline germanium, the junction transistor looks like a small piece of material with three soldered connections.

Commercial junction transistors are made by both the grown technique and the alloy technique and in both *p-n-p* and *n-p-n* polarities. In general, these commercially available transistors have similar charac-

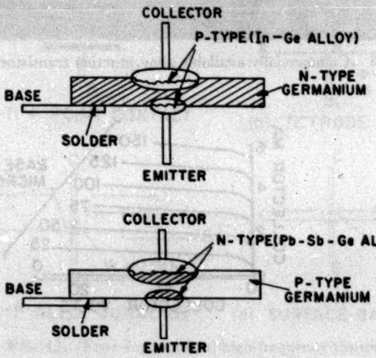


FIG. 9. Construction of alloy junction transistors.

teristics and one may consider them all as approximately equivalent. A photo is shown in Fig. 10 and a composite characteristic in Fig. 11. There are, of course, differences in the method of encapsulation, in the size, and in details of the currents and voltages for particular operating conditions. The power amplification at low frequencies is about 10,000 times, or 100 times greater than the point-contact unit. The noise at low frequencies is much less and compares favorably with electron tubes. The frequency performance of commercial junction transistors is not as good as point-contact types, perhaps a tenth as high.

Among present-day commercial semiconductor devices mention should be made of the photodiode, the phototransistor, and even the

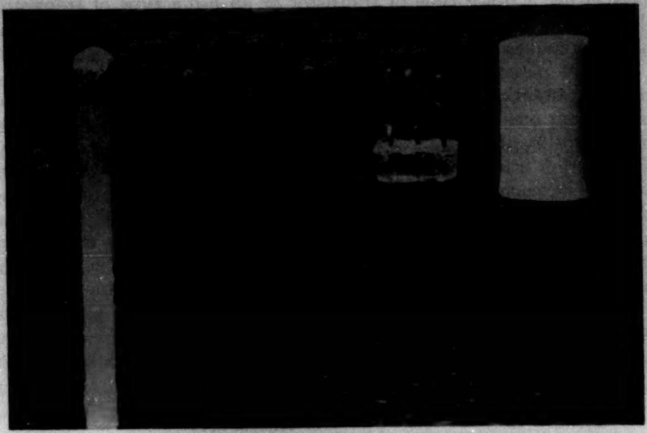


FIG. 10. Commercially available alloy junction transistor.

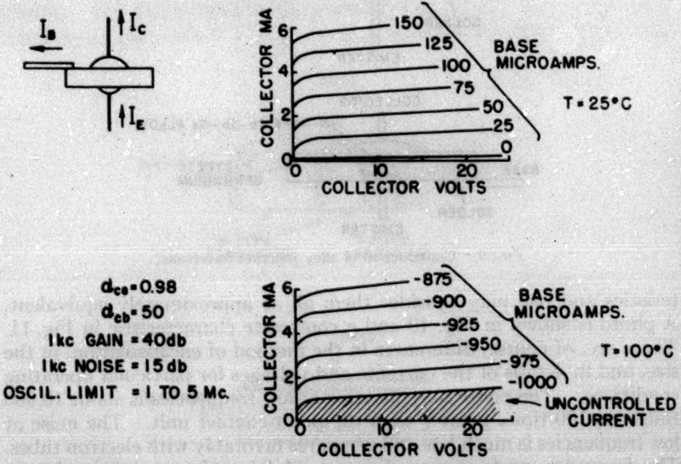


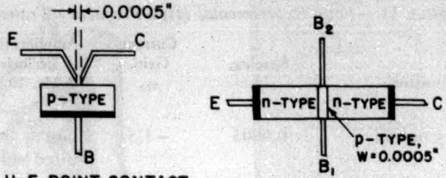
FIG. 11. Composite characteristics of commercially available junction transistors. The currents and voltages are positive for *n-p-n* units and are negative for *p-n-p* units.

vidicon television pickup tube, because all these use semiconducting or photoconducting materials of the same general nature. Although these are outside the scope of the present paper, it should be kept in mind that the future may see a great increase in the importance of solid-state light-controlled devices in electronics.

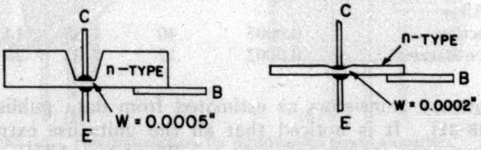
PRESENT LABORATORY DEVELOPMENTS

So far, commercially available devices have been described. We will now consider devices which are still in the experimental stage in the laboratory.

The first important limitation of commercial transistors is their limited frequency response. There has been much work to overcome this and Fig. 12 shows four experimental developments. In the point-contact transistor, by use of very close point spacing, low resistance germanium of the *p*-type, it has recently been possible to attain an upper oscillation limit of over 400 megacycles (29). (See Fig. 12(*a*).) Unfortunately, the point-contact transistor is not easily applied to amplifier use.



(a) V-H-F POINT CONTACT (b) TETRODE



(c) H-F ALLOY JUNCTION (d) SURFACE BARRIER

FIG. 12. Four experimental high-frequency transistors.

A second development in improving frequency response is the grown junction *tetrode* transistor also shown in Fig. 12(*b*). This consists of a very small grown junction arrangement with two base connections on opposite sides of the base layer (30). By placing a bias between these leads, transistor operation occurs only in a very small area near one of the leads. This reduces the base resistance and diffusion capacitance sufficiently so that high-frequency operation is improved.

A third improved high-frequency transistor retains the practical advantages of the alloy technique (**31**), as shown in Fig. 12(*c*). Again one notes the use of extremely close spacing between the electrodes but, at the same time, the germanium wafer tapers into a thick section so as to retain very low base resistance. The junctions themselves are very small in area.

Still another development in high-frequency transistors is the one which has been called the "surface barrier" transistor (**28**), Fig. 12(*d*). As with the other high-frequency types, this also makes use of low-resistance germanium, close spacing between the electrodes but, with this construction, the electrodes are plated rather than being metallic points or crystallized germanium.

Table II shows the approximate performance of the four types of high-frequency transistors as estimated from data published on the types (**28–31**). It is noticed that all the units use extremely close spacing between contacts or junctions. The *p*-type VHF point-contact transistor is not well suited for amplification but it tops all other transistors in its upper limit of oscillation. The grown junction tetrode has excellent performance at high frequencies with some sacrifice, however, in low frequency performance as indicated by the lower current gain and reduced amplification at 0.5 megacycles. Because an extremely small bar of germanium is used and two base connections are required, the grown junction tetrode is not easily fabricated. The high-frequency alloy junction transistor, on the other hand, is an extension of the more conventional alloy junction transistor which retains normal low frequency performance and yet operates well at high frequencies. Such a device, for example, could be universally used without sacrifice in voltage handling ability or performance. The surface barrier transistor makes up for the reduced quality of the plated emitter contact by an even closer spacing than the other types. As a result, it has reduced voltage handling ability and low power dissipation. As with the

TABLE II.—*Four Experimental High-Frequency Transistors.*

Transistor	Spacing, in.	Current Gain, α_{cb}	Amplification, decibels 0.5 Mc.	Amplification, decibels 10 Mc.	Highest Reported Oscil., Mc.
V-H-F Point Contact	0.0005	−1.5	not suited	not suited	420
Grown Junction Tetrode	0.0005	6	32	20	130
H-F Alloy Junction	0.0005	40	38	14	75
Surface Barrier	0.0002	12	33	20	70

tetrode, there is some sacrifice in low-frequency performance in favor of high-frequency performance.

Another limitation of present commercial transistors is power handling ability. Fortunately, all the junction types of transistor are capable of operation at considerably higher current density values than normally necessary for small signal applications. The chief problem for a power transistor is dissipation of the additional internally generated heat. This can be done in many ways (32), of which the simplest are either liquid cooling, Fig. 13(*a*), or conduction cooling, Fig. 13(*b*). In the latter, the germanium wafer and/or its junction electrode is fastened to a piece of conducting copper which can radiate or conduct the heat to cooler environments. These particular units are experimental germanium ones which dissipate approximately one to three watts without auxiliary heat conduction from the metal envelope. By careful attention to the heat conduction means from the wafer to the envelope, and auxiliary cooling, considerably higher dissipations have been attained experimentally in the same size construction. Power junction transistors of this general type are capable of peak currents of about one ampere and maximum operating voltages of the order of 40 volts. In a Class B connection, wherein the transistor dissipation is held to a minimum, maximum power outputs of the order of five watts can be achieved with two units operated from a 12-volt supply.

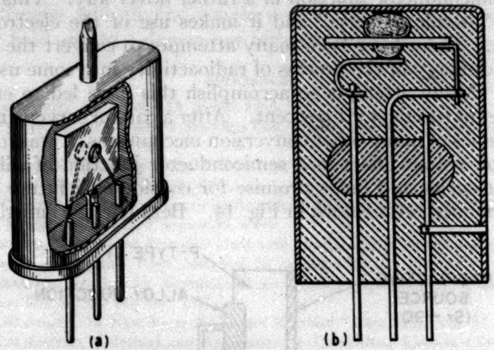


FIG. 13. Two constructions for experimental power transistors, (*a*) liquid cooled, (*b*) conduction cooled.

Another laboratory development is the silicon junction transistor. Silicon single-crystal material of satisfactory quality has been available for some time and its application to alloy junction transistors required the development of suitable techniques. An alloy junction transistor using silicon has been developed which has current amplification factors of 20 or more and a power gain of between 35 and 40 db. at low frequencies. Such a transistor exhibits the expected freedom of changes in uncontrolled current with temperature; in fact, the uncontrolled current is so small as to be hardly detectable. Operation appears to be feasible at temperatures well in excess of 100° C. The perfection of presently available silicon crystals, and the techniques of surface treatment, have not reached the stage common with germanium and considerably better results are yet to be anticipated.

Laboratory results have been obtained with many other special forms of transistor but they have not yet reached as high a degree of practicality as those outlined herein. One may expect, however, further interesting and novel devices in the future.

It may be of interest to mention a recent laboratory development using a semiconductor junction in a rather novel way. This has been called an "atomic battery," and it makes use of the electron-voltaic effect (33). There have been many attempts to convert the electrical and kinetic energy of the process of radioactivity into some useful form of power. Many attempts to accomplish this have led to efficiencies of the order of less than 0.1 per cent. After a careful survey and experimental studies of many other conversion mechanisms, it was found that the electron voltaic effect in a semiconductor junction of silicon gave higher efficiencies and holds promise for considerable future improvement. The method is shown in Fig. 14. Beta particle emitting radioactive material is placed near an *n-p* alloy junction of silicon. The bombardment produces a low voltage at high current in the junction. The radioactive half life of the strontium 90 material is of the order of 20 years, but radiation damage to the semiconductor material must also be considered. Nevertheless, the future may see such sources of power, particularly in connection with transistorized equipment which operates on such extremely low powers.

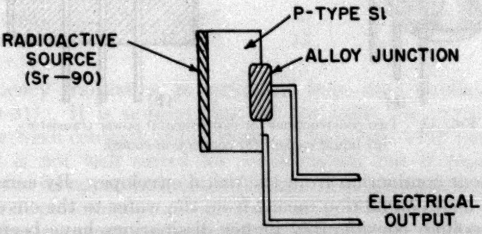


Fig. 14. The electron-voltaic effect used to convert radioactivity to electrical power in a *p-n* junction.

Available radioactive power $=4\times10^{-3}$ watts/curie
Available radioactive current $=6\times10^{-9}$ amp/curie
Battery output current $=10^{-3}$ amp/curie

THE FUTURE OF SEMICONDUCTOR DEVICES

As to the transistor, it will improve with respect to uniformity, reliability and cost. At the same time the frequency range will be extended, and the power levels will increase to the point where even high-power industrial applications will be possible. Multi-electrode and special-function transistors will also be developed.

Many who have seen at first hand the rapidity with which the transistor has developed, believe that this device is but the first of many remarkable solid-state devices. The close relationship of photo effects and semiconduction can be expected to lead to useful improvements in all types of light-sensitive and light-producing devices.

The most basic steps, however, will come only as a result of improved materials. In this area, the chemist, the physicist, the ceramicist and the metallurgist will all find ample opportunity to contribute to the electronic field and to a degree not hitherto achieved.

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ANALYSIS OF CONTINUITY OF ONE PHASE IN A POWDER MIXTURE OF TWO PHASES

BY

F. FORSCHER[1]

ABSTRACT

The paper contains a theoretical analysis of the continuity of one phase (powder A) in a mixture of two powders (A and B). It is assumed that the two powders are well mixed so that particles of powder A are randomly distributed in powder B. The continuity condition for powder A is expressed by the probability that the separation between two particles of this phase vanishes. For spherical particles of unequal sizes the continuity condition can be stated as the probability that the distance between the centers of any two particles of powder A equals the sum of their radii.

General equations are developed and a powder mixture of equal spherical particles is discussed as a special case.

INTRODUCTION

The problem to be analyzed in this paper is the condition of continuity of a powder A when it is randomly distributed in a matrix made up of powder B. In order to establish a physical picture we may think of powder A as a good conductor and powder B as a poor conductor of electricity. The degree of continuity of powder A would be proportional to the over-all conductivity of the compound powder mixture.

The assumption is made that powder A is composed of spherical particles of various radii, the distribution of which is known. We want to find analytically an expression of the degree of continuity of powder A. Continuity is here expressed as the probability that pairs of particles of powder A have radii, the sum of which just equals the distance between their centers.[2] Throughout the following analysis we shall employ capital letters for dimensions of space, that is, distance between particle centers, and lower case letters for particle dimensions. The analysis that follows can be divided into three steps. Consider one particle of powder A. The first step is to express the probability of finding the center of the nearest neighbor a distance R from the center of the particle under consideration. Let this probability be denoted by $P(R)$. The second step is to express the probability of finding two particles from powder A, the radii of which add up to some fixed distance c. Let this probability be denoted by $P(r_1 + r_2 = c)$. These two probabilities constitute independent events and hence the probability of their simultaneous occurrence is the product of the individual probabilities and is denoted as $P(R, c)$. As the third step, the condition of continuity is expressed as the probability $P(c, R = c)$ which occurs when the central distance R equals the sum of the two radii c.

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[2] Since we are dealing with a statistical assembly we expect to find continuity expressed in terms of probabilities. On the other hand, if we were dealing with an ordered assembly we would expect to find an exact numerical answer for any given geometrical configuration. An ordered assembly implies that we have control over the location and size of the individual particles. In practice, we cannot realize such conditions (**3**).[3] Interesting observations with respect to an ordered assembly are found in the literature (**1**, **2**).

[3] The boldface numbers in parentheses refer to the references appended to this paper.

The analysis in this paper is designed to answer the following problem. Given two powders of known size distribution, add increasing amounts of powder A into powder B and mix well; when will A become continuous? This *first* continuity is expressed as probability $P(c, R = c)$. If more of powder A is added to the mixture, A will become *more* continuous. When the percentage by volume is 50 per cent A and 50 per cent B, both powders are equally continuous. Adding more A to the mixture will make A still more continuous and B become less and less continuous, until at some high percentage of A (*not* 100 per cent), powder B becomes discontinuous. The range of percentages of A between first continuity to complete continuity is not considered in the analysis.

DISTRIBUTION OF THE NEAREST NEIGHBOR IN A RANDOM DISTRIBUTION OF PARTICLES (STEP 1)

The probability of finding the nearest neighbor at a distance R equals the probability that no particle exists interior to R, times the probability that a particle does exist in the spherical shell between R and $R + dR$. Accordingly, the function $P(R)$ must satisfy the relation

$$P(R)dR = \left[1 - \int_0^R P(R)dR\right] 4\pi R^2 n dR$$

where n denotes the average number of particles per unit volume. We derive from above (4)

$$P(R) = 4\pi R^2 n e^{-\frac{4}{3}\pi R^3 n}, \tag{1}$$

since

$$\int_0^\infty P(R)dR = 1.$$

A number of interesting aspects of Eq. 1 are discussed below. To find the average distance R between particles in this random assembly we take the first moment (4)

$$\bar{R} = \int_0^\infty RP(R)dR = \int_0^\infty 4\pi R^3 n^{-\frac{4}{3}\pi R^3 n} dR = \frac{1}{(\frac{4}{3}\pi n)^{\frac{1}{3}}} \int_0^\infty x^{\frac{1}{3}} e^{-x} dx$$

where $x = \frac{4}{3}R^3 n$. Note that

$$T(k + 1) = \int_0^\infty x^k e^{-x} dx \quad \text{(Gamma function).}$$

Hence

$$\bar{R} = 0.554 n^{-\frac{1}{3}}, \qquad \text{or} \qquad n = \left(\frac{0.554}{\bar{R}}\right)^3. \tag{2}$$

Let us compare Eq. 2 to the extreme case of an *ordered* assembly, namely the case of close packed equal spheres. n spheres per unit volume fill about 74 per cent of the unit volume (1). Hence

$$n\tfrac{4}{3}\pi r^3 = 0.74 \qquad \text{and} \qquad r = 0.56 n^{-\frac{1}{3}}. \tag{3}$$

It is seen that $\bar{R}$, the average distance between particle centers in Eq. 2, and r, the *radius* of equal size close packed spheres, are nearly identical.

Two transformations of variables are of interest:

(*a*) The probability in terms of space volume (about the central point) within which the nearest neighboring point is expected.

From $P(R)dR = P(V)dV$ we find

$$P(V) = P(R)\frac{dR}{dV} = P(R)\frac{dR}{d(\frac{4}{3}\pi R^3)} = \frac{P(R)}{4\pi R^2} \tag{4}$$

$$P(V) = ne^{-Vn}. \tag{5}$$

(*b*) The probability in terms of the logarithm of R. This transformation is useful because the frequency distribution of particle size in terms of the logarithm of their radii r is approximately normal (5). From $P(\ln R)d(\ln R) = P(R)d(R)$ we find

$$P(\ln R) = 3Vne^{-Vn}. \tag{6}$$

DISTRIBUTION OF TWO PARTICLES FROM A RANDOM ASSEMBLY THE RADII OF WHICH ADD UP TO A CONSTANT c (STEP 2)

Consider a powder A from which we first take one particle of radius r_1 and then another particle of radius r_2. It is assumed that we have a large number of particles so that the original distribution of particle size is not changed upon removal of the first particle. Hence we have chosen particles 1 and 2 from two identical independent distributions of particle sizes $P(r_1)$ and $P(r_2)$. The probability of the simultaneous occurrence of any r_1 and r_2 is the product of their respective probabilities.

$$P(r_1, r_2) = P(r_1)P(r_2). \tag{7}$$

Equation 7 represents a bulge-shaped surface over the $r_1 - r_2$ plane, symmetrical with respect to $r_1 = r_2$. The ordinate under the surface $P(r_1, r_2)$ represents the probability of simultaneous occurrence of r_1 and r_2 (Fig. 1). The probability of the simultaneous occurrence of two radii which add up to a constant c is clearly a function of c. It is represented in Fig. 1 by the area which is the intersection of the volume under the surface $P(r_1, r_2)$ and the plane passing through the line $r_1 + r_2 = c$. Since the original distributions of $P(r_1)$ and $P(r_2)$ are

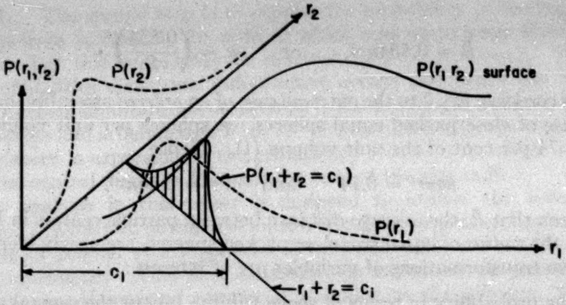

FIG. 1.

identical, it follows that every area represented by $P(r_1 + r_2 = c)$ is symmetrical with respect to its midpoint at $r_1 = r_2$. The distribution of these areas as a function of c is the desired probability $P(r_1 + r_2 = c)$.

The same surface can also be represented in terms of two new variables c_1 and c_2 (Fig. 2). The transformation equations are

$$\begin{aligned} r_1 + r_2 &= c_1 & \tfrac{1}{2}(c_1 + c_2) &= r_1 \\ r_1 - r_2 &= c_2 & \tfrac{1}{2}(c_1 - c_2) &= r_2 \end{aligned} \qquad (8)$$

where

$$\begin{aligned} 0 \leqslant c_1 &\leqslant \infty \\ -c_1 \leqslant c_2 &\leqslant +c_1. \end{aligned} \qquad (9)$$

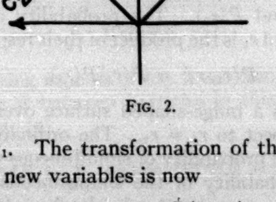

FIG. 2.

Note that $c = \sqrt{2}\, c_1$. The transformation of the probability function from the old to the new variables is now

$$P(c_1, c_2) = \frac{P(r_1, r_2)}{\dfrac{\partial(c_1, c_2)}{\partial(r_1, r_2)}} \qquad (10)$$

where $\frac{\partial(c_1, c_2)}{\partial(r_1, r_2)}$ is the Jacobian of the transformation

$$\begin{vmatrix} \frac{\partial c_1}{\partial r_1} & \frac{\partial c_1}{\partial r_2} \\ \frac{\partial c_2}{\partial r_1} & \frac{\partial c_2}{\partial r_2} \end{vmatrix} = \begin{vmatrix} 1 & 1 \\ 1 & -1 \end{vmatrix} = -2 \tag{11}$$

in which the minus sign has no meaning and can be dropped (6).

Particle size distribution when plotted on the basis of the logarithm of the particle dimension, appears often as a normal distribution (3). Thus

$$P(t) = \frac{1}{\sqrt{2\pi}} e^{-t^2/2} \tag{12}$$

where

$$t = \frac{\ln r - m}{\sigma}$$

$$m = \frac{\sum n \ln r}{\sum n}$$

$$\sigma = \left[\frac{\sum n(\ln r - m)^2}{\sum n}\right]^{\frac{1}{2}}.$$

The combined probability $P(t_1, t_2)$ would be a surface over the t_1–t_2 plane with central symmetry at $t = 0$.

$$P(t_1, t_2) = \frac{1}{2\pi} e^{-\frac{1}{2}(t_1^2+t_2^2)}. \tag{13}$$

The condition that $r_1 + r_2 = c$ becomes now

$$e^m(e^{\sigma t_1} + e^{\sigma t_2}) = c \tag{14}$$

from $t_1 = \frac{\ln r_1 - m}{\sigma}$ and $t_2 = \frac{\ln r_2 - m}{\sigma}$.

PROBABILITY THAT TWO NEAREST NEIGHBORS HAVE A CENTRAL DISTANCE EQUAL TO THE SUM OF THEIR RADII (STEP 3)

The simultaneous occurrence of nearest particles, distance R apart, having their radii add up to a constant c is expressed by the product of the respective probabilities. The combined probability $P(R, c)$ can be thought of as a surface over the $R - c$ plane which will show *no* symmetry with respect to $R = c$. It will be affected by the density n of powder A through $P(R)$ and by the original grain-size distribution of powder A through $P(c)$.

The line $R = c$ subdivides the $R - c$ plane into two areas. The area where $R > c$ represents all probabilities where the distance between particles is too large to afford contact, while the area where $R < c$

represents mathematically the probabilities of a too close approach. The latter one is a physical impossibility. Particles which would fall into this area will separate themselves until the distance between their centers equals the sum of their radii, that is, until $R = c$. If we consider the final configuration of powder A as a random assembly in mathematical space, in spite of the mutual accommodation with respect to their position in physical space, the foregoing analysis still holds. The probability $P(R, c)$ must equal 1 when integrated over the pertinent region, that is, over $R \geqslant c$. In any case, the degree of continuity is expressed by the probability when $R = c$. Continuity M is then equal to

$$M = \int_0^\infty P(c_1 R = c) dc. \tag{15}$$

For a practical application of foregoing analysis we would first have to evaluate $P(R)$ with density n as parameter. With a given histogram for a particular powder size distribution it is possible to evaluate $P(r_1 + r_2 = c)$.

It is seen that a numerical value for M of Eq. 15 can be found, either analytically or, in any case, numerically. A desirable value of continuity M will have to be set for any given application as an acceptance limit.

DISCUSSION OF RANDOMNESS AND THE CASE OF EQUAL SPHERICAL PARTICLES

It was pointed out in the introduction that the application of this analysis implies a random distribution of powder A in the container holding the mixture A plus B. *This condition is not satisfied if the total volume which powder A occupies is large relative to the container volume.* Hence, for randomness we must have

$$\frac{\sum_1^N n_i \frac{4}{3}\pi r_i^3}{V_c} \ll 1$$

where V_c is the container volume, N is the number of classes and n_i is the number of particles in the ith class. For a discussion of this condition it is convenient to assume *one* class, that is, a constant particle size r. Under this condition the above equation becomes

$$\frac{n \frac{4}{3}\pi r^3}{V_c} \ll 1.$$

The numerator of this inequality may become large if we have few particles of large size (condition on r) or many particles of small size (condition on n).

It is easily seen that the first case, where the particle size approaches the container size, must invalidate random distribution. We must also remember that in the derivation of the distribution function for the nearest neighbor $P(R)$ the quantity $n4\pi R dR$ indicated the number of particles we expect to find within a thin shell of thickness dR, which would not be physically possible if the particle size is large.

In the second case, where we consider small particles, we can find the effect of density by the following consideration. Equation 5 can be considered as the probability of finding the nearest points (particle center) on the surface of a *constant* sphere V when the density (n) can assume different values. What density will give us the highest probability of finding the nearest neighboring point on V? By differentiating and equating to zero, we find

$$\frac{dP}{dn} = 0 = ne^{-Vn}\left(\frac{1}{n} - V\right) \qquad \text{or} \qquad n = \frac{1}{V}.$$

This means that when n becomes larger than $1/V$, the chance of finding a point *within* V is so good that the probability of finding the nearest neighbor on the surface of V decreases.

Let $V = \frac{4}{3}\pi(2r)^3$. This surface is the location of the centers of all possible spheres (radius r) touching a center sphere (radius r) located at the origin (center of V). In a closely packed (ordered) arrangement, twelve spheres can be arranged on V which gives, according to Eq. 3, n (ordered) $= \dfrac{1}{5.66r^3}$. But from $n = \dfrac{1}{V}$

$$n = \frac{3}{32\pi r^3} = \frac{1}{33.5r^3}.$$

Comparison of the two values of n leads to the conclusion that the randomness is preserved as long as n is about $\frac{1}{6}$ of n (ordered). This means that *two* (out of possible twelve) nearest neighbors may be of type A. If n is larger than two out of twelve, randomness is not preserved; that is, particles which would most probably fall inside V are pushed to their final location on the surface of V.

For an aggregate of equal-size spheres we can draw the following conclusion. If the mixture consists of $\frac{1}{6}$ A and $\frac{5}{6}$ B, then every particle will most probably be touched by two particles of type A; since "every" particle includes particles of type A, powder A becomes a continuous phase. We can state this conclusion differently. In a mixture of equal-size spherical particles, A is probably discontinuous if the ratio of A to B is below $\frac{1}{5}$. *Both* A and B are continuous where $\frac{A}{B}$ exceeds this ratio and eventually B becomes discontinuous if $\frac{B}{A}$ falls below $\frac{1}{5}$.

Equation 15 expresses the condition for two particles of A to touch when the particle size is not uniform. The contact probability of groups of three or more particles of A is not considered. The probability of forming chains is also not considered.

Figure 3 shows two samples of synthetic *plane* mixtures of equal-sized A's and B's. The pattern appears to confirm the analysis. It seems very unlikely that a random mixture of 50-50 or even 40-60 will exhibit discontinuity of A's. This is easily visualized if one tries to extend the plane pattern into the third dimension. Similar arrays may be constructed for other synthetic mixtures of equal-size spheres.

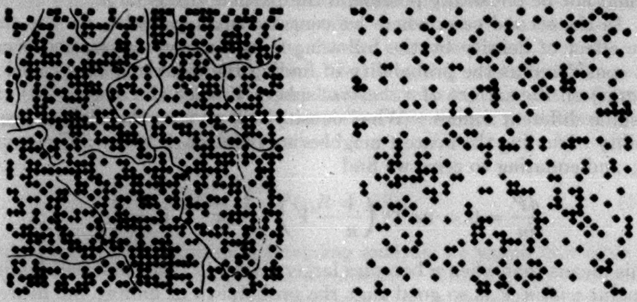

FIG. 3.

Arrangement of a plane mixture of 50 per cent A and 50 per cent B in an array of 40 by 40 spaces using tables of random numbers. A (0, 2, 4, 6, 8) and B (1, 3, 5, 7, 9).

It is improbable that the outlined "grain boundaries" are continuous in the direction perpendicular to the paper.

Arrangement of a plane mixture of 20 per cent A and 80 per cent B in an array of 40 by 40 spaces using tables of random numbers. A (0, 1) and B (2, 3, 4, 5, 6, 7, 8, 9).

The probability of plane chains of 5 to 10 A's is apparent.

Although no numerical work is included, it is hoped that the approach to the problem of continuity as presented in the above analysis is of some help to the workers in this field.

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ANALYSIS OF NONLINEAR SYSTEMS WITH MORE THAN ONE DEGREE OF FREEDOM BY MEANS OF SPACE TRAJECTORIES

BY

Y. H. KU[1]

INTRODUCTION

Physical systems of real importance usually have several degrees of freedom and contain also nonlinear elements. In some cases, nonlinear elements are purposely introduced to insure better performance of the system. The famous Blasius equation $x''' + xx'' = 0$ is a nonlinear differential equation of the third order (**1**, **2**).[2] In studying the laminar boundary layer problem of a rotating body of revolution, Illingworth (**3**) gave four other differential equations involving one dependent variable each and coefficients that depend upon the solution of the Blasius function. In the study of nuclear reactors, a system of seven differential equations may be encountered (**4**). While the first equation is a nonlinear differential equation for the neutron density, the other six equations are for the six delayed neutron emitters. For these seven first-order differential equations, we either have to solve for the seven variables or to solve a single nonlinear differential equation of the seventh order. In either case, we need a 7-dimensional phase space for a complete representation of the problem.

In a paper recently published (**5**), the writer extended his acceleration plane method (**6**, **7**) to the solution of high order nonlinear differential equations. More recently, the writer solved several problems involving multi-loop circuits with either nonlinear elements or nonlinear coupling (**8**, **9**). It is a logical development that the idea of multi-dimensional space trajectory has come forth. It is hoped that the n-dimensional phase-space method may enlarge our views and develop our concepts in solving high-order or multi-variable nonlinear problems, just as the phase-plane method has rendered valuable service in solving second-order nonlinear systems. Several examples of space trajectories are here given for the first time.

SPACE TRAJECTORIES

We shall start our discussion with a 3-dimensional phase space. Consider first a second-order nonlinear differential equation, say a Van der Pol equation. There are three quantities involved: x the dependent variable and its first and second time derivatives x' and x''. In any physical event, x, x' and x'' all start from their initial values, that is, their values at $t = 0$. After a certain time interval, x, x' and x'' assume or change to another set of values. As time goes on, x, x' and x'' assume more and more sets of values until the end of time, or $t = \infty$. This physical event can be represented by a space trajectory in a 3-dimensional phase space showing the relations among x, x' and x'', while the time t is implicit. This space trajectory has three projections: one in the $x' - x$ plane, one in the $x'' - x'$ plane, and the third in the $x'' - x$ plane. As x'' is expressible in terms of x and x' by the second-order nonlinear differential equation

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

$$x'' + f(x', x) + f_1(x) = F(t), \tag{1}$$

it is only necessary to find the projection in one plane, for example the $x' - x$ plane. Thus the $x' - x$ trajectory in the two-dimensional $x' - x$ phase plane is sufficient to represent the particular physical event expressible by Eq. 1. The phase-plane equation is given by

$$\frac{dx'}{dx} = \frac{x''}{x'} = \frac{F(t) - f(x', x) - f_1(x)}{x'}. \tag{2}$$

Taking the Van der Pol equation

$$x'' - (1 - x^2)x' + x = 0, \tag{1a}$$

the phase-plane equation is

$$\frac{dx'}{dx} = \frac{x''}{x'} = \frac{(1 - x^2)x' - x}{x'}. \tag{2a}$$

The space trajectory showing the relations among x, x' and x'' is shown in Fig. 1. The $x' - x$ trajectory is shown in dotted lines, with x values as ordinates and x' values as abscissae. The $x'' - x'$ and $x'' - x$ trajectories are shown in Ref. 7.

THE BLASIUS EQUATION

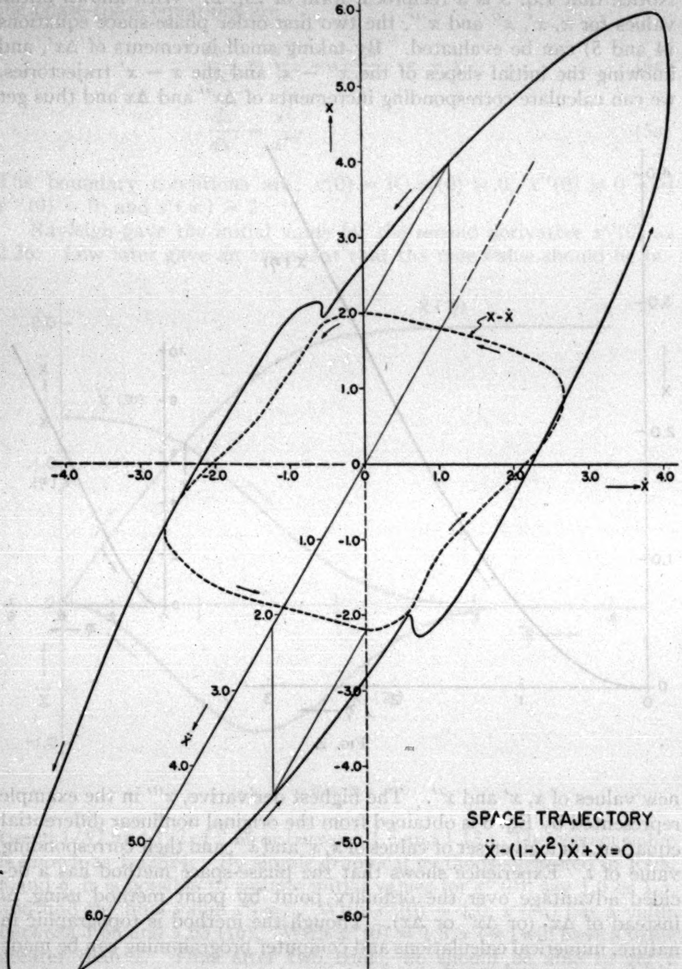
We shall next consider a third-order nonlinear differential equation of the following general form

$$x''' + \phi(x', x)x'' + f(x', x) + f_1(x) = F(t). \tag{3}$$

The phase-space equations are:

$$\frac{dx''}{dx'} = \frac{x'''}{x''} = \frac{F(t) - \phi(x', x)x'' - f(x', x) - f_1(x)}{x''} \tag{4}$$

$$\frac{dx}{dx'} = \frac{x'}{x''}. \tag{5}$$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3.0
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SPACE TRAJECTORY
$\ddot{X}-(1-X^2)\dot{X}+X=0$

FIG. 1

Notice that Eq. 5 is a reciprocal form of Eq. 2. With known initial values for x, x', x'' and x''', the two first-order phase-space equations (4 and 5) can be evaluated. By taking small increments of $\Delta x'$, and knowing the initial slopes of the $x'' - x'$ and the $x - x'$ trajectories, we can calculate corresponding increments of $\Delta x''$ and Δx and thus get new values of x, x' and x''. The highest derivative, x''' in the example represented by Eq. 3 is obtained from the original nonlinear differential equation, for a given set of values of x, x' and x'', and their corresponding value of t. Experience shows that the phase-space method has a decided advantage over the ordinary point by point method using Δt instead of $\Delta x'$ (or $\Delta x''$ or Δx). Though the method is topographic in nature, numerical calculations and computer programming can be made with accuracy and speed.

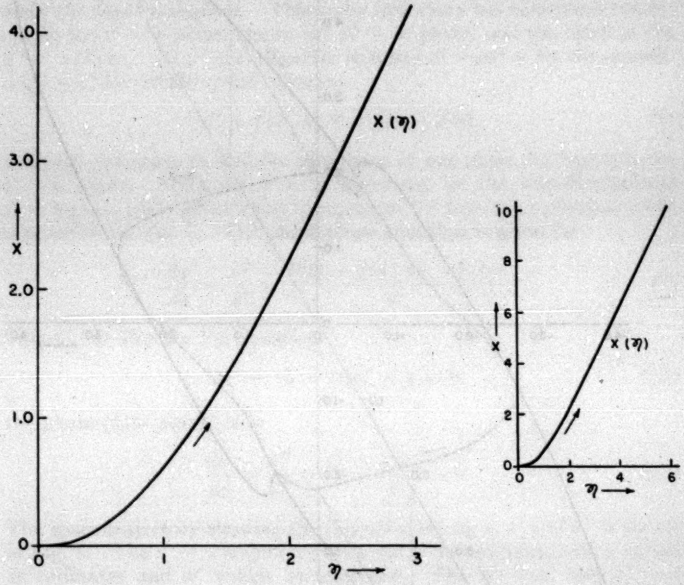


Fig. 2.

Taking the Blasius equation

$$x''' + xx'' = 0, \tag{3a}$$

the phase-space equations are

$$\frac{dx''}{dx'} = \frac{x'''}{x''} = \frac{-xx''}{x''} = -x \tag{4a}$$

$$\frac{dx}{dx'} = \frac{x'}{x''}. \tag{5a}$$

The boundary conditions are: $x(0) = 0$, $x'(0) = 0$, $x''(0) \neq 0$ and $x'''(0) = 0$; and $x'(\infty) = 2$.

Rayleigh gave the initial value for the second derivative $x''(0)$ as 2.26. Low later gave an argument that the true value should lie between $1/\sqrt{2}$ and $1/2$ of 2.26 or between 1.6 and 1.13. The correct value is known as 1.32824. By simple graphical methods suggested in Refs. 5 and 6, it is possible to assume initial values for $x''(0)$, say 1.0 or 1.5, and find the final value $x'(\infty)$. With $x''(0) = 1.0$, $x'(\infty)$ has a value between 1.66 and 1.63 (10). With $x''(0) = 1.5$, $x'(\infty)$ will have a value greater than 2. Thus after two trials, we should be able to get a reasonably correct value for $x''(0)$ around 1.25 or 1.30.

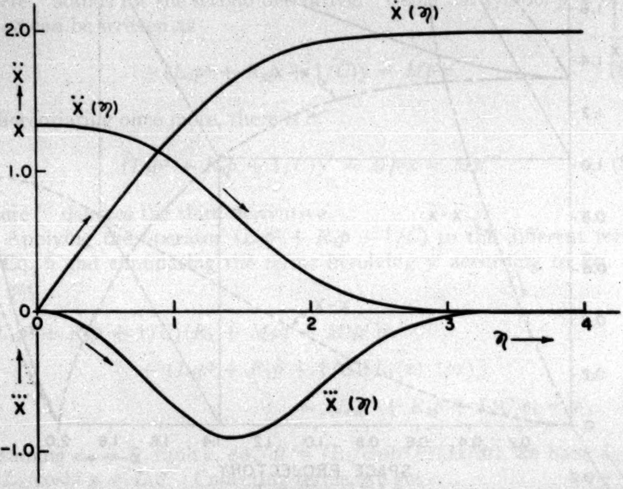


FIG. 3.

Notice that the independent variable in Eq. 3a is not the time, t, but the parameter, η, defined by $(1/2)(U_1/N_*X)^{1/2}Y$, where X and Y are the axes of plane of motion, with X along the axis of the plane wall and Y perpendicular to it; U_1 is the uniform value of the velocity component along X; and N_* is the uniform value of kinematic viscosity.

The $x(\eta)$, $x'(\eta)$, $x''(\eta)$ and $x'''(\eta)$ curves are shown in Figs. 2 and 3. Since $x(\eta)$ goes to infinity as η increases to infinity, a space trajectory with x', x'' and x''' as coordinates is more interesting than a space trajectory with x, x' and x'' as coordinates. The space trajectory showing the relation among the first, second and third derivatives of the Blasius function is shown in Fig. 4. Note that the final boundary conditions are: $x''' = 0$, $x'' = 0$, $x' = 2.0$; and x as shown in Fig. 2.

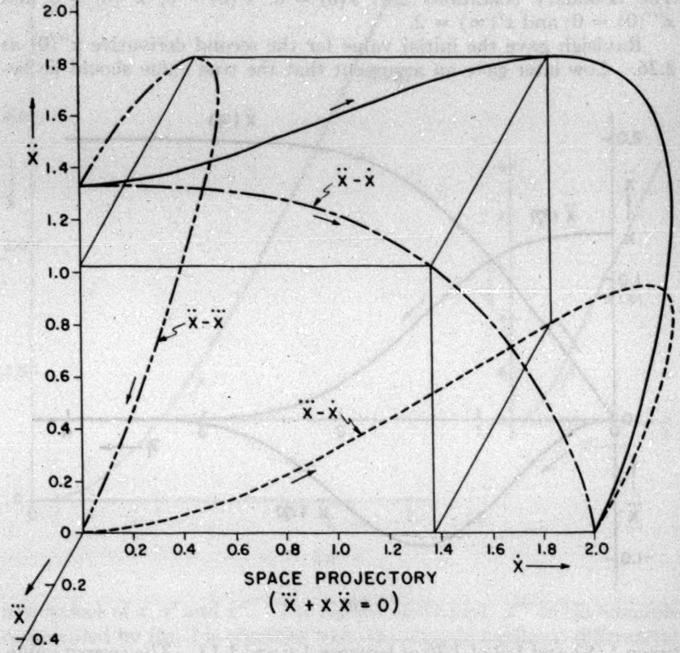


FIG. 4.

SYSTEMS WITH TWO DEGREES OF FREEDOM

We shall now proceed to the analysis of nonlinear systems with two degrees of freedom. Taking the circuit shown in Fig. 5, let x and y be the two dependent variables. The differential equations are:

$$R_1x + L_1(x)x' + Mx' - My' = e_1 \tag{6}$$

$$R_2y + L_2y' + (1/C)y^{-\prime} - Mx' = 0 \tag{7}$$

where $'$ stands for the first derivative and $^{-\prime}$ stands for the integral with respect to t. $L_1(x)$ is the nonlinear element in the primary circuit. Differentiating Eq. 7 with respect to time, we get

$$L_2y'' + R_2y' + (1/C)y - Mx'' = 0 \tag{8}$$

where $''$ stands for the second derivative. Using the symbol $p = d/dt$, Eq. 8 can be written as

$$(L_2p^2 + R_2p + 1/C)y = Mp^2x. \tag{8a}$$

Differentiating once more, there is

$$(L_2p^2 + R_2p + 1/C)y' = Mp^3x = Mx''' \tag{8b}$$

where $'''$ denotes the third derivative.

Applying the operator $(L_2p^2 + R_2p + 1/C)$ to the different terms in Eq. 6 and eliminating the terms involving y' according to Eq. 8*b*, we get

$$\begin{aligned}[(L_2p^2 + R_2p + 1/C)(R_1 + Mp) - M^2p^3]x \\ + (L_2p^2 + R_2p + 1/C)[L_1(x)\cdot(px)] \\ = (L_2p^2 + R_2p + 1/C)e_1 = F_1.\end{aligned} \tag{9}$$

Assuming $\phi_1 = L_1 \tanh x$, $d\phi_1/dt = (L_1/\cosh^2 x)(dx/dt)$, we have $L_1(x) = L_1/\cosh^2 x = L_1\beta$. Collecting terms, we get

$$\begin{aligned}(a_3 + b_3\beta)x''' + (a_2 + b_2\beta + 3b_3\beta'x')x'' \\ + (a_1 + b_1\beta)x' + b_2\beta'(x')^2 + b_3\beta''(x')^3 + a_0x = F_1\end{aligned} \tag{10}$$

where

$$a_3 = (L_2 - M)M, \quad b_3 = L_1L_2, \quad a_2 = R_1L_2 + R_2M, \quad b_2 = R_2L_1,$$

$$a_1 = R_1R_2 + M/C, \quad b_1 = L_1/C, \quad a_0 = R_1/C,$$

$$\beta = 1/\cosh^2 x, \quad \beta' = d\beta/dx = -2\alpha\beta, \quad \alpha = \tanh x, \text{ and}$$

$$\beta'' = d^2\beta/dx^2 = 2\beta(2\alpha^2 - \beta).$$

Equation 10 is a modification of Eq. 3. The phase-space equations are

$$\frac{dx''}{dx'} = \frac{x'''}{x''} = \frac{\begin{array}{r} F_1 - (a_2 + b_2\beta + 3b_3\beta' x')x'' \\ - (a_1 + b_1\beta)x' - b_2\beta'(x')^2 - b_3\beta''(x')^3 - a_0 x \end{array}}{(a_3 + b_3\beta)x''} \tag{11}$$

$$\frac{dx}{dx'} = \frac{x'}{x''}. \tag{12}$$

Putting in the numerical values (11): $R_1 = R_2 = 0.5$, $L_1 = M = 1$, $L_2 = 2$, $C = 1$ and $e_1 = 1$, we get

$$\frac{dx''}{dx'} = \frac{\begin{array}{r} 1 - (1.5 + 0.5\beta - 12\alpha\beta x')x'' - (1.25 + \beta)x' \\ + \alpha\beta(x')^2 - 4\beta(2\alpha^2 - \beta)(x')^3 - 0.5x \end{array}}{(1 + 2\beta)x''}. \tag{11a}$$

Assuming no initial currents and charges, the initial values are:

$$\begin{array}{lll} x = 0 & y = 0 & y^{-\prime} = 0 \\ x' = 2/3 & y' = 1/3 & \\ x'' = -5/18 & y'' = -2/9 & \\ x''' = 67/162 & y''' = 31/324. & \end{array}$$

The initial slopes of the trajectories are:

$$\frac{dx''}{dx'} = \frac{x'''}{x''} = -\frac{67}{45} \qquad \frac{dy''}{dy'} = \frac{y'''}{y''} = -\frac{31}{72}$$

$$\frac{dx}{dx'} = \frac{x'}{x''} = -\frac{12}{5} \qquad \frac{dy}{dy'} = \frac{y'}{y''} = -\frac{3}{2}.$$

The space trajectory showing the relations among x, x' and x'' is given in Fig. 5. The projections in the $x'' - x'$ plane, in the $x' - x$ plane and in the $x'' - x$ plane are also given in the same figure. A similar space trajectory showing the relations among y, y' and y'' can be constructed from the following relations:

$$\begin{aligned} y''' &= x'''/2 - y''/4 - y'/2 \\ y'' &= x'/2 + (1 + \beta)x'' - 2\alpha\beta(x')^2 \\ y' &= x/2 + (1 + \beta)x' - 1 \\ y &= x'' - 2y'' - y'/2 \\ y^{-\prime} &= x' - 2y' - y/2. \end{aligned}$$

TWO-LOOP SYSTEM WITH SINUSOIDAL FORCING FUNCTION

As another illustration we shall consider the coupled circuit as shown in Fig. 7 with a sinusoidal voltage suddenly applied to the primary

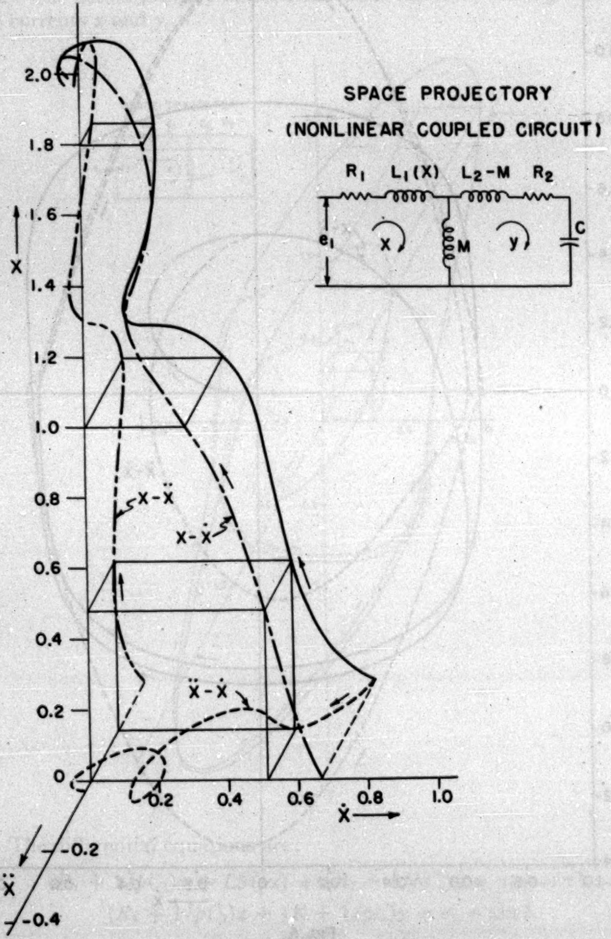
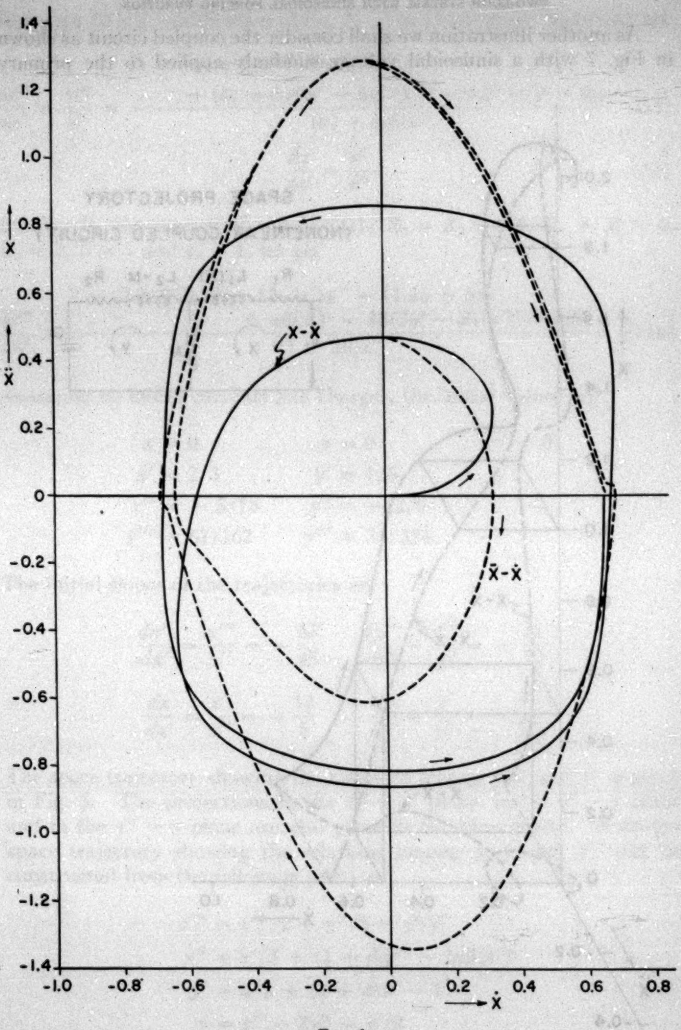


FIG 5


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
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x
ẍ
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ẍ-ẋ
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
ẋ

FIG. 6.

circuit or loop and with a nonlinear coupling between the two loops. The two dependent variables x and y are chosen to represent two loop currents as shown. Notice that the current x passes through the nonlinear coupling element and the current y passes through the secondary loop. The actual primary current can be obtained by adding the two loop currents x and y.

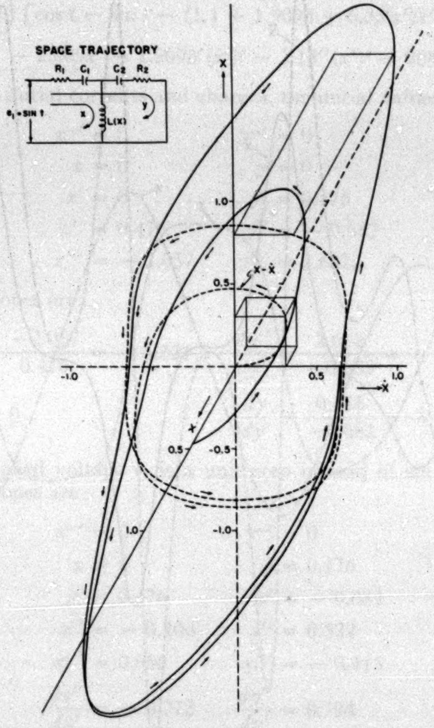
SPACE TRAJECTORY
R1
C1
C2
R2
e1 = SIN t
x
y
L(X)
X
1.0
0.5
X-Ẋ
-1.0
0.5
1.0
Ẋ
Ẍ
0.5
-0.5
1.0
-1.0

FIG. 7.

The differential equations are:

$$(R_1 + 1/pC_1)x + L\beta(px) + (R_1 + 1/pC_1)y = e_1 = \sin t \qquad (13)$$

$$(R_1 + 1/pC_1)x + (R + 1/pC)y = e_1 = \sin t \qquad (14)$$

$$(R_2 + 1/pC_2)y = L\beta(px) \qquad (15)$$

where R_1 and R_2 represent the resistances in the primary and secondary circuits, $R = R_1 + R_2$, C_1 and C_2 represent the capacitances, $1/C = 1/C_1 + 1/C_2$, and $L\beta$ represents the nonlinear inductance coupling, with $\beta = 1/\cosh^2 x$. Any two of the above three equations are sufficient for the solution of the problem.

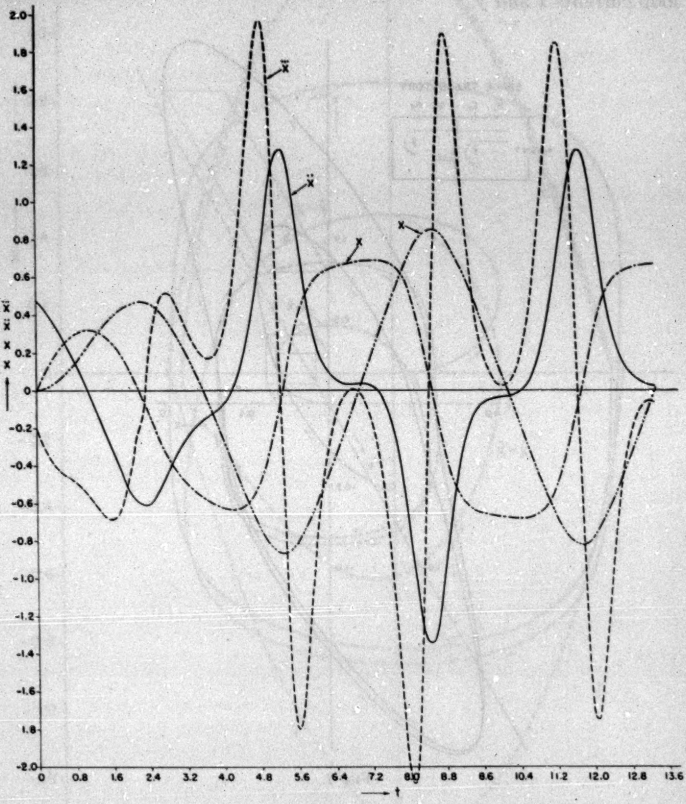

FIG. 8.

Elimination of y and its derivatives leads to a third order nonlinear differential equation in x:

$$b_3\beta x''' + (a_2 + b_2\beta + 3b_3\beta' x')x'' + (a_1 + b_1)x' + b_2\beta'(x')^2 + b_3\beta''(x')^3 + a_0 x = R_2 e_1'' + e_1'/C_2 = F_1 \qquad (16)$$

where $b_3 = RL$, $a_2 = R_1R_2$, $b_2 = L/C$, $a_1 = R_2/C_1$, $b_1 = R_1/C_2$, and $a_0 = 1/C_1C_2$.

Putting in the numerical values: $R_1 = 1.1$, $R_2 = 1.0$, $C_1 = 1.1$, $C_2 = 1.0$, $L = 1.0$, $R = R_1 + R_2 = 2.1$, $1/C = 1/C_1 + 1/C_2 = 1/1.1 + 1/1 = 1.909$, $e_1 = \sin t$, $e_1' = \cos t$, $e_1'' = -\sin t$, and $F_1 = R_2e_1'' + e_1'/C_2 = -\sin t + \cos t$, Eq. 16 gives

$$x''' = \left(\frac{1}{2.1\beta}\right)[\cos t - \sin t - (1.1 + 1.909\beta + 6.3\beta'x')x'' - 2.009x' - 1.909\beta'(x')^2 - 2.1\beta''(x')^2 - 0.909x]. \quad (16a)$$

Assuming no initial currents and charges, the initial values are:

$$\begin{array}{rl} x^{-\prime} = 0 & y^{-\prime} = 0 \\ x = 0 & y = 0 \\ x' = 0 & y' = 0.476 \\ x'' = 0.476 & y'' = -0.682 \\ x''' = -2.057 & y''' = 2.682. \end{array}$$

The initial slopes are:

$$\frac{dx''}{dx'} = \frac{-2.057}{0.476} = -4.321 \qquad \frac{dy''}{dy'} = \frac{2.682}{-0.682} = -3.932$$

$$\frac{dx}{dx'} = 0 \qquad \frac{dy}{dy'} = \frac{0.476}{-0.682} = -0.698.$$

If the applied voltage e_1 is a unit step instead of $\sin t$, the initial values and slopes are:

$$\begin{array}{rl} x^{-\prime} = 0 & y^{-\prime} = 0 \\ x = 0 & y = 0.476 \\ x' = 0.476 & y' = -0.682 \\ x'' = -0.206 & y'' = 0.522 \\ x''' = 0.056 & y''' = -0.415 \\ \dfrac{dx''}{dx'} = -0.272 & \dfrac{dy''}{dy'} = 0.794 \\ \dfrac{dx}{dx'} = -2.310 & \dfrac{dy}{dy'} = 1.306. \end{array}$$

The trajectories for both cases will be quite different.

The $x - x'$ and $x'' - x'$ trajectories for $e_1 = \sin t$ are shown in Fig. 6. The space trajectory showing the relations among x, x' and x'' is shown in Fig. 7. Notice that the projection of the space trajectory in Fig. 7 in its $x - x'$ plane (shown in dotted lines) is the same as the $x - x'$ trajectory in Fig. 6 (shown in solid line). The instantaneous curves for $x(t)$, $x'(t)$, $x''(t)$, and $x'''(t)$ are shown in Fig. 8. Notice that F_1, the forcing function on the right hand side of Eq. 16, is equal to $(\cos t - \sin t)$ and may be added to Fig. 8. It is of interest to compare the space trajectory in Fig. 7 with the limit cycle (in three dimensions) shown in Fig. 1.

SYSTEMS WITH FOUR DEGREES OF FREEDOM

If we consider a two-loop system with R, L and C elements in both loops and with a mutual inductance coupling M, we get a fourth order differential equation. Consider another system with three loops, we have three dependent variables, x, y and z. If we have inductance coupling between the first and second loops, and capacitance coupling between the second and third loops, and we have only R and L in the other branches, the resultant high order differential equation is of the fourth order. In general, if we have a first-order differential equation in the first loop, a second-order differential equation in the second loop, and another second-order differential equation in the third loop, the highest order of the resultant single differential equation is equal to or less than the sum of the orders of the differential equations. In the above three-loop example, $n_1 = 1$, $n_2 = 2$, and $n_3 = 2$, and hence $n \leq (n_1 + n_2 + n_3) \leq 5$, or, $n = 4$ in this particular case, where n denotes the order of the differential equation.

If we have *four* first-order differential equations, we have four dependent variables, say, w, x, y and z. The highest order of the resultant single differential equation is $n = (n_1 + n_2 + n_3 + n_4) = 1 + 1 + 1 + 1 = 4$. Thus the simplest problem in a system with four degrees of freedom leads to a differential equation of the fourth order. In the above, we have not mentioned specifically about the existence of nonlinearities either in the branches or couplings. In fact, in aerodynamics or nuclear reactors problems, we find nonlinear terms in the given differential equations instead of nonlinearities in the loops or circuits. However, it may be said in general that the order of nonlinear differential equations is to be defined in the same way as the order of linear differential equations. Nonlinearities in the circuits or loops or nonlinear terms in the original differential equations *do not* as a rule *increase* the order of the resultant high order differential equation. As an illustration, take a nonlinear inductance $L(x)$, the inductance drop or induced emf. is given by $L(x)(dx/dt)$ instead of $L(dx/dt)$, where L is a constant. The single differential equation $Rx + L(x)x' + Mx' - My' = e_1$ (see Eq. 6) is still of the first order. If we have three other first-order differential equations, the resultant single differential equation will be of the fourth order, with the presence of a number of nonlinear terms due to $L(x)$.

In a nuclear reactor problem, if we assume three delayed neutron emitters, we get a system of *four* first-order differential equations with four degrees of freedom. Let the four variables be the neutron density, w, and x, y and z, representing the total number of delayed neutron emitters per cubic centimeter in the three emitters. Neglecting the effect of Fermi age for the sake of simplicity, the differential equations may be given in the following form:

$$w' = f(w) + x + y + z \tag{17}$$

$$x' + a_1 x = b_1 w \tag{18}$$

$$y' + a_2 y = b_2 w \tag{19}$$

$$z' + a_3 z = b_3 w \tag{20}$$

where the constants a_1, a_2 and a_3 are related to the delay constants, and the constants b_1, b_2 and b_3 are related to the fractions of neutrons which are delayed. The nonlinear term is given by $f(w)$ in Eq. 17 and may be approximated by $f(w) = a_0 w^2 - b_0 w$.

Elimination of x, y and z leads to a fourth order nonlinear differential equation in w

$$w'''' = f_3(w'', w', w) \cdot w''' + f_2(w'', w', w) + f_1(w', w) + f_0(w). \tag{21}$$

Applying the n-dimensional phase-space method, we can write down the following phase-space trajectory equations

$$\frac{dw'''}{dw''} = \frac{w''''}{w'''} \tag{22}$$

$$\frac{dw'}{dw''} = \frac{w''}{w'''} \tag{23}$$

$$\frac{dw}{dw''} = \frac{w'}{w'''}. \tag{24}$$

Given the initial values for w and its high derivatives (these can be obtained from Eqs. 17–20 if the initial values of w, x, y and z are known), we can proceed to plot the trajectories $w''' - w''$, $w' - w''$ and $w - w''$ from their initial slopes, taking small increments in $\Delta w''$. Notice that by assuming a small step in $\Delta w''$, we can determine from Eqs. 22–24 the corresponding steps in $\Delta w'''$, $\Delta w'$ and Δw. With known increments for w and its first, second and third derivatives, we can calculate the fourth or highest derivative according to Eq. 21. With the new value of w'''' known, we can calculate the new slope of the $w''' - w''$ trajectory according to Eq. 22. The other slopes can be obtained from the new values of w''', w'' and w' according to Eqs. 23 and 24.

The reader may be reminded of the procedure in the phase-plane method for solving second-order nonlinear differential equations (**12, 13, 14**). From Eq. 2, it is possible to determine the slope of the $x' - x$

trajectory in the middle of the chosen interval, Δx, by solving for $\Delta x'$ from the following relation

$$\left(\frac{dx'}{dx}\right)_{\text{at } x = x_0 + \frac{\Delta x}{2}} = \frac{\Delta x'}{\Delta x}$$
$$= \frac{F(t_0 + \Delta t/2) - f(x_0' + \Delta x'/2,\, x_0 + \Delta x/2) - f_1(x_0 + \Delta x/2)}{x_0' + \Delta x'/2}. \tag{25}$$

For a given Δx, one can solve for $\Delta x'$, while $\Delta x = x_{av}'(\Delta t) = (x_0' + \Delta x'/2)\Delta t$ gives $\Delta t = (\Delta x)/(x_0' + \Delta x'/2)$.

It is sufficient to say here that the accuracy of the slopes can be assured if one takes small steps and make checks back and forth whenever in doubt. Experience has shown that it is worthwhile to plot the highest derivative against the variable or any of its lower derivatives to insure against errors. If a forcing function is a function of time, then a plot of the highest derivative against time is also convenient.

CONCLUSIONS AND REMARKS

An n-dimensional phase-space method is here proposed for the solution of an n-th order nonlinear differential equation or the solution of n first-order differential equations involving n dependent variables and hence having n degrees of freedom. Since it is immaterial whether the final differential equation of the n-th order is obtained from n first-order differential equations or from n' differential equations such that the sum of their orders add up to n, we may think of an n-th order differential equation as one representing a simple system of first-order differential equations having n degrees of freedom. In this generalized n-degree of freedom system, we have two possible choices to make. The first choice is to work with all n dependent variables. The second choice is to work with one chosen dependent variable plus its derivatives from the first derivative to the $(n - 1)$th derivative, as the n-th (the highest) derivative is expressible in terms of the other quantities. The present paper only discusses the second choice, though a companion paper may be submitted for discussing the first choice.

Take a fourth order nonlinear differential equation as representing the resultant expression for a system with four degrees of freedom. In the original equations, let w, x, y and z be the dependent variables, and let these equations be of the first order as shown in Eqs. 17–20. According to the first choice, we can try to get a space representation of these four quantities in a four-dimensional space. According to the second choice, we have succeeded in representing a fourth order differential equation like Eq. 21 in a four-dimensional space with three phase-space trajectories defined by three first-order differential equations like Eqs. 22–24. If there is a way of constructing the four-dimensional space trajectory, the coordinates we have chosen are w, w', w'' and w''', or x, x', x'' and x'''. Take the x-set for discussion. If x represents physically the displacement, x' the velocity, x'' the acceleration, x''' will represent the rate of acceleration. In ordinary mechanics, it is reasonable to imagine that the displacement, the velocity, and the acceleration all have something to do with the behavior of a dynamic system say with one or more degrees of freedom. It is only one step further to extend this concept from a three-variable problem to a four-variable problem, just as we extend our concept from a one degree of freedom problem to a problem with four degrees of freedom. The extension to n variables for an n degree of freedom problem or to another set of n variables for the n-th order differential equation is hence logical.

In the phase-plane method, many concepts have been developed regarding singular points, stability, limit cycle, etc. It is suggested here that similar efforts should be made in the phase-space method. Take the four space trajectories given in this paper as illustrations. Figure 5 shows a space trajectory that settles down to a stable point at $x=2$, $x'=0$ and $x''=0$. Figure 4, on the other hand, shows a space trajectory that has a stable point *only* in the $x' - x'' - x'''$ sub-space at $x' = 2$, $x'' = 0$ and $x''' = 0$. Figure 1 is the familiar limit cycle for the Van der Pol equation, while Fig. 7 shows the building up of oscillations in a two-loop nonlinear system. It may be mentioned that experimental trajectories can be photographed from oscilloscopes and computers can be utilized in solving the phase-space equations with speed and accuracy.

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Science Hobby Kits Developed for Children.—Scientists are probably unable to estimate the number of times their young sons or daughters have asked questions such as:

"What makes it rain?"

"What do they mean by blood pressure?"

"How does a radio work?"

"Where is gold found?"

"What makes a telescope bring things closer to us?"

Knowing that the parent is engaged in a field of science, the child naturally expects a quick answer. But the answers to such questions, as any man or woman of science will agree, involve a considerable amount of technical explanation, most of which is usually far above the comprehension of the average embryo scientist unless certain basic materials are available for demonstration.

With the aid of a new group of science instruction aids now on the market, it won't be long before children will be performing experiments which will provide most of the answers they seek. Called "American Industry" Educational Hobby Kits, the new kits are five in number, and are being distributed exclusively to the educational and laboratory supply fields by Central Scientific Company, Chicago, under an agreement with Industrial America, Inc., coordinators of the hobby kit program.

Each of the kits is prepared by a leading industrial firm in collaboration with the Museum of Science and Industry and *Encyclopaedia Britannica*. The kits and their producers are: Electronics Kit made by RCA; Optical Kit produced by the American Optical Society; Rock Detective Kit manufactured by the Gemological Institute of America; Weather Kit put together by the Taylor Instrument Companies; and the Medical Training Kit by Bauer & Black.

Youngsters can learn the hows and whys of each science by building their own scientific instruments from materials contained in the kits. Each kit is also equipped with a comprehensive instructional booklet, prepared under the direction of the *Encyclopaedia Britannica*. The booklet explains and illustrates in detail the fundamentals of the science for which the kit was prepared and gives step-by-step directions for the numerous experiments that can be performed.

The kits will prove particularly valuable for use by science clubs and scout groups, as well as the home workshop or school classroom demonstration. A number of children can work with a single kit or parents can demonstrate the various experiments to a group. As children learn by doing, however, turning the kits over to them is preferable.

The five kits now available from Central Scientific Company are designed for children from 8 to 18 years of age and are actually only the forerunners for what is hoped to be a complete series carrying the junior scientists right into college technical programs. Each of the present kits is labeled with the number "1," that is Electronics Kit No. 1, Weather Kit No. 1, etc. The coordinators of the program plan to expand them into more advanced study so that eventually there will be kit numbers 2, 3, 4, etc.

Furthermore, it was pointed out that other major industrial firms have shown the desire to participate in the program by producing kits of their own. It is hoped that in the months to come the hobby kits will cover every major field of science.

DISTURBANCES IN THE INDUCTION MACHINE DUE TO BROKEN SQUIRREL-CAGE RINGS

BY

E. MISHKIN[1]

1. INTRODUCTION

The rotor of the squirrel-cage induction machine consists of axial bars closed on both sides by short circuiting rings. The magnetic field induced by the currents, flowing in the stator windings induce currents in these bars which find closing paths in the short-circuiting rings. A broken squirrel-cage end ring which occurs occasionally as a result of faulty material or manufacture should be rather regarded as a limit case of a local increase in ring resistance. It is desirable to develop the theory of the interrupted-ring machine, as it not only accounts for all disturbances associated with this particular type of breakdown but also allows a better insight into the mechanism of the disturbances characterising all kinds of asymmetry of the squirrel-cage, and can be used for the determination of the various waves of the electro-magnetic field, the stator currents and torques.

Using a machine model which, while omitting the finer details of construction, preserves all principal characteristics, it is possible to formulate the theory as a physical interpretation of a mathematical analysis. In order to facilitate the calculation, a perfectly symmetrical case—both short-circuiting end rings are diametrically interrupted—is assumed. The procedure for other, less symmetrical cases, is identical, although more cumbersome in some details.

2. THE MACHINE-MODEL WITH SMOOTH ROTOR AND STATOR[2]

In order to facilitate the calculations, let us consider a three-phase asynchronous machine with its symmetrically wound stator and rotor both made of steel sheets of perfect permeability ($\mu \rightarrow \infty$). We shall assume the stator to be covered with an axial-current carrying surface, preserving the linear current density of the real stator; while the rotor is wrapped in a very thin conducting layer of thickness δ and specific conductivity σ (see Fig. 1). Having arrived at the results, we may allow $\delta \rightarrow 0$ and $\sigma \rightarrow \infty$ so as to have the product $\delta \cdot \sigma$ remain finite. We shall also neglect the curvature of the machine and choose a right-hand Cartesian coordinate system x, y, z so as to have the x-axis coincide with the inner surface of the stator, the y-axis directed towards the rotor and the z-axis parallel to the shaft of the machine.

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[2] F. Ollendorff, "Einheitliche Theorie der Drehfeldmaschinen an Hand eines Modelles," *Archiv für Elektrotechnik* (Berlin), Vol. XXIV, p. 130 (1930).

The air gap, d, is to be assumed appreciably longer than the real one, so as to compensate for the fact that both the stator and rotor conductors have been located at their respective outer surfaces, while actually embedded in the iron cores.

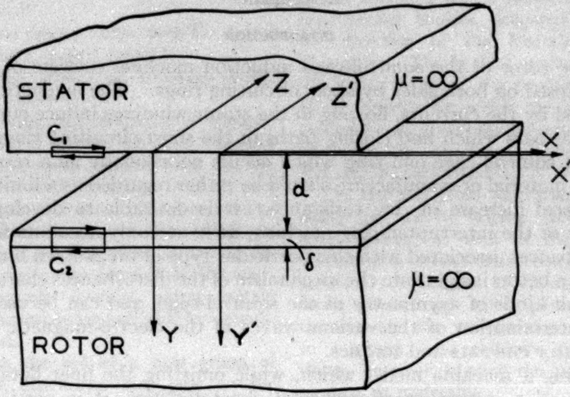

FIG. 1. Model of developed asynchronous machine.

3. THE AIR GAP ELECTRO-MAGNETIC FIELD OF A NORMAL MACHINE [3]

Let E (volt/m) be the intensity of the electric field and H (amp/m) the intensity of the magnetic field

$$E = Re(\mathbf{E}e^{j\omega t}); \quad H = Re(\mathbf{H}e^{j\omega t}). \tag{1}$$

where Re denotes the real part of the complex quantity. In all following calculations Re and the factor $e^{j\omega t}$ will normally be omitted. Neglecting the end effect, we shall have stator and rotor currents flowing in the direction of the z-axis, and consequently a single component of $\mathbf{E}$, in the same direction. $\mathbf{H}$ consists of two components, $\mathbf{H}_x$ and $\mathbf{H}_y$ in the x and y directions, respectively. Maxwell's second equation, applied to the air gap area, reads

$$\nabla \times E = -\frac{\partial B}{\partial t} = -\mu_0 \frac{\partial H}{\partial t} = -j\omega\mu_0 H, \tag{2}$$

where B is magnetic induction, and μ_0 is permeability of free space.

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[3] E. Mishkin, "Theory of the Induction Machine Derived Directly from Maxwell's Field Equations," D. Sc. Thesis, Haifa, Hebrew Institute of Technology, 1951, pp. 14–19.

When developed as follows,

$$\begin{vmatrix} i & j & k \\ \dfrac{\partial}{\partial x} & \dfrac{\partial}{\partial y} & \dfrac{\partial}{\partial z} \\ 0 & 0 & \mathbf{E} \end{vmatrix} = -\,j\omega\mu_0\mathbf{H}, \tag{2a}$$

it yields

$$\mathbf{H}_x = \frac{-1}{j\omega\mu_0}\cdot\frac{\partial\mathbf{E}}{\partial y};\quad \mathbf{H}_y = \frac{1}{j\omega\mu_0}\cdot\frac{\partial\mathbf{E}}{\partial x}. \tag{3}$$

Maxwell's first equation, applied to the air gap area,

$$\nabla\times\mathbf{H} = 0;\quad \begin{vmatrix} i & j & k \\ \dfrac{\partial}{\partial x} & \dfrac{\partial}{\partial y} & \dfrac{\partial}{\partial z} \\ \mathbf{H}_x & \mathbf{H}_y & 0 \end{vmatrix} = 0;\quad \frac{\partial\mathbf{H}_y}{\partial x} - \frac{\partial\mathbf{H}_x}{\partial y} = 0 \tag{4}$$

results—in conjunction with Eq. 3—in the Laplace differential equation of **E** for the air gap

$$\frac{\partial^2\mathbf{E}}{\partial x^2} + \frac{\partial^2\mathbf{E}}{\partial y^2} = 0. \tag{5}$$

There are two boundary conditions to be complied with, one on the inner surface of the stator and the other on the outer surface of the rotor, corresponding to the two physical factors governing the working state of the machine, *viz*: the voltage connected to the stator and the load (torque) carried by the rotor. These two boundary conditions follow the application of the integral form of the field equation $\int\mathbf{H}\cdot d\mathbf{s} = I$ (I = total current) to the contours C_1 and C_2 (see Fig. 1).

$$\mathbf{H}_{x(y=0)} = -\,\mathbf{A}_{st} \tag{6}$$

$$\mathbf{H}_{x(y=d)} = \mathbf{A}_r \tag{7}$$

$\mathbf{A}_{st}$ and $\mathbf{A}_r$ are the respective linear current densities of the stator and rotor. As it is well known, $\mathbf{A}_{st}$ is composed of harmonics 1, 5, 7 $\cdots$ the first harmonic being

$$\mathbf{A}_{st} = \mathbf{A}_m\cdot e^{-j\frac{\pi}{\tau}x} = \frac{\sqrt{2}}{2}\cdot wI\,\frac{4}{\pi}\cdot\frac{\pi}{\tau}\cdot\frac{3}{2}\cdot q\cdot g\cdot e^{-j\frac{\pi}{\tau}x} \tag{8}$$

where τ denotes the pole pitch, w is the number of conductors in one slot, ω is the angular frequency, q the number of slots per pole and phase, and g the winding factor. Let v denote the rotor's peripheral speed,

v_s the synchronous speed and s the motor's slip. The relation between them is

$$v = v_s(1 - s) = \omega \frac{\tau}{\pi} (1 - s). \tag{9}$$

The expressions

$$x = x' + v \cdot t = x' + \frac{\tau}{\pi} (1 - s)\omega t; \quad y = y'; \quad z = z' \tag{10}$$

define a new rotating coordinate system, parallel to the stationary one, and at rest with respect to the rotor. All quantities in this rotor-fixed coordinate system will be denoted by respective primes.

As we are considering a squirrel cage short-circuited rotor and neglecting the "end effect," we should postulate, in accordance with Ohm's law

$$\mathbf{A}_r' = \sigma \cdot \delta \cdot \mathbf{E}'_{(y=d)}. \tag{11}$$

Considering the first harmonic (8) only, the solution of (5) can be written as

$$\mathbf{E} = e^{-j\frac{\pi}{\tau}x} \cdot (K^+ \cdot e^{\frac{\pi}{\tau}y} + K^- \cdot e^{-\frac{\pi}{\tau}y}), \tag{12}$$

where K^+ and K^- are integration constants defined by the boundary conditions. Substituting their values (see Appendix 1) we obtain the electric field $\mathbf{E}$ in the air gap

$$\mathbf{E} = A_m \cdot j\omega\mu_0 \frac{\tau}{\pi} \cdot \frac{\sigma\delta js\omega\mu_0 \frac{\tau}{\pi} \cdot \sinh \frac{\pi}{\tau} (y - d) - \cosh \frac{\pi}{\tau} (y - d)}{\sinh \frac{\pi}{\tau} d + \sigma\delta js\omega\mu_0 \frac{\tau}{\pi} \cdot \cosh \frac{\pi}{\tau} d} \cdot e^{-j\frac{\pi}{\tau}x}. \tag{13}$$

It should be borne in mind that only the fundamental harmonic of $\mathbf{A}_{st}$ has been taken into consideration. As it is well known, $\mathbf{A}_{st}$ consists of harmonics of the order 1, 5, 7, 11, 13, $\cdots$ each contributing to a corresponding term of $\mathbf{E}$.

4. THE MACHINE WITH BOTH END-RINGS DIAMETRICALLY INTERRUPTED

This is a perfectly symmetrical case with the calculation considerably simplified. It can nevertheless show in principle all effects produced by any arbitrary interruption of the end rings. The field equations being linear, the behaviour of the machine can be deduced by the superposition, on a normal machine, of a similar one with four hypothetical generators inserted at the points of interruption of the rings. These generators supply a current equal in amplitude but opposite in sign to the current flowing through the same points when the rings are undamaged. No voltage, of course, is applied to the stator of the machine with the hypothetical generators. Figure 2 shows the developed rotor with the rotating rotor-fixed coordinate system $ox'y'z'$. The generators are inserted at $x' = 0$ and $x' = p\tau$ where the rings are interrupted (p is the number of pole pairs). These hypothetical generators (their voltage being $\mathbf{U} \cdot e^{js\omega t}$) induce a (peripheral) electric field $\mathbf{E}_x'$ in the end rings. Its distribution along circumference of the rotor is shown in Fig. 3 where $2a$ denotes the width of the interrupted rings.

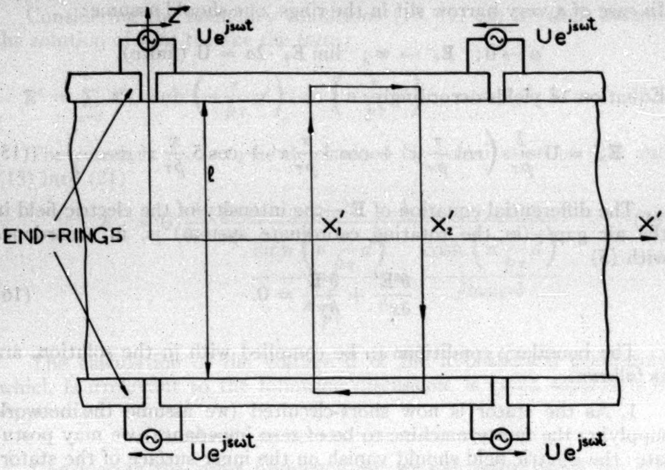

FIG. 2. Developed rotor with hypothetical generators.

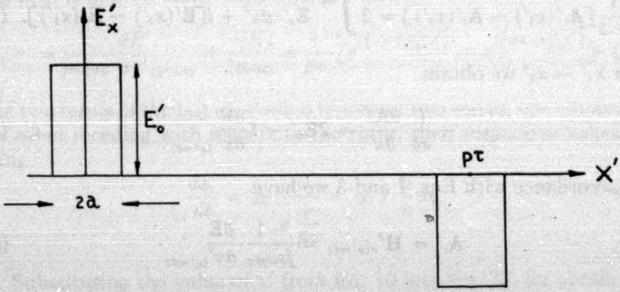

FIG. 3. The intensity curve of the circumferential electric field.

The development of this function into a Fourier series gives

$$\mathbf{E}_x' = \mathbf{E}_0' \cdot \frac{4}{\pi}\left(\sin\frac{\pi}{p\tau}a\cdot\cos\frac{\pi}{p\tau}x' + \frac{1}{3}\sin 3\frac{\pi}{p\tau}a\cdot\cos 3\frac{\pi}{p\tau}x' + \cdots\right). \tag{14}$$

In case of a very narrow slit in the rings, one should assume:

$$a \to 0; \quad \mathbf{E}_0' \to \infty; \quad \lim \mathbf{E}_0'\cdot 2a = \mathbf{U} \text{ (finite).}$$

Equation 14 yields accordingly:

$$\mathbf{E}_x' = \mathbf{U}\cdot\frac{2}{p\tau}\cdot\left(\cos\frac{\pi}{p\tau}x' + \cos 3\frac{\pi}{p\tau}x' + \cos 5\frac{\pi}{p\tau}x' + \cdots\right). \tag{15}$$

The differential equation of $\mathbf{E}'$—the intensity of the electric field in the air gap—(in the rotating coordinate system) is, in accordance with (5)

$$\frac{\partial^2\mathbf{E}'}{\partial x'^2} + \frac{\partial^2\mathbf{E}'}{\partial y'^2} = 0. \tag{16}$$

The boundary conditions to be complied with in the solution, are as follows:

1. As the stator is now short-circuited (we assume the network supplying the faulty machine to be of zero impedance) we may postulate: the electric field should vanish on the inner surface of the stator, that is,

$$\mathbf{E}'_{(y'=0)} = 0. \tag{17}$$

2. We shall omit the ohmic resistance of the end rings. The contour integral of the electric field, taken along the rectangle shown in Fig. 3, yields:

$$l\cdot\frac{1}{\sigma\cdot\delta}[\mathbf{A}_r'(x_1') - \mathbf{A}_r'(x_2')] = 2\int_{x_1'}^{x_2'}\mathbf{E}_x'\cdot dx' + l[\mathbf{E}'(x_1') - \mathbf{E}'(x_2')]. \tag{18}$$

For $x_1' \to x_2'$ we obtain

$$-\frac{l}{\sigma\delta}\cdot\frac{\partial\mathbf{A}_r'}{\partial x'} = 2\mathbf{E}_x' - l\frac{\partial\mathbf{E}'}{\partial x'}_{(y'=d)}. \tag{19}$$

In accordance with Eqs. 7 and 3 we have

$$\mathbf{A}_r' = \mathbf{H}'_{x(y'=d)} = \frac{-1}{js\omega\mu_0}\cdot\frac{\partial\mathbf{E}}{\partial y'}_{(y'=d)}. \tag{20}$$

(It should be borne in mind that the frequency of the rotor currents in the rotating coordinate system is $s\omega$, not ω.) Equation 19 now yields

$$2\mathbf{E}_z' = l\left[\frac{\partial \mathbf{E}'}{\partial x'} + \frac{1}{js\omega\mu_0\sigma\delta}\cdot\frac{\partial^2\mathbf{E}'}{\partial x'\partial y'}\right]_{(y'=d)} \qquad (21)$$

Considering the boundary conditions (15, 17, 21) we shall assume the solution of (16) to take the form:

$$\mathbf{E}' = \sum_{n=1}^{\infty} K_n\cdot\sinh\left(n\frac{\pi}{p\tau}y'\right)\cdot\sin\left(n\frac{\pi}{p\tau}x'\right); \quad n = 1, 3, 5, \cdots. \qquad (22)$$

The constant K_n is to be determined by substitution of (22) and (15) into (21)

$$K_n = \mathbf{U}\cdot\frac{4}{l\pi^2}\cdot\frac{p\tau}{n^2}\cdot\frac{1}{\dfrac{\sinh\left(n\dfrac{\pi}{p\tau}d\right)}{n\dfrac{\pi}{p\tau}} + \dfrac{\cosh\left(n\dfrac{\pi}{p\tau}d\right)}{js\omega\mu_0\tau\delta}}. \qquad (23)$$

The calculation of the voltage $\mathbf{U}$ of the hypothetical generators, which is irrelevant to the following discussion, is given separately in Appendix 2.

5. CALCULATION OF THE PARASITIC STATOR CURRENTS

Considering the rotor frequency $s\omega$, we can write down the n'th harmonic of $\mathbf{E}'$ in accordance with (22)

$$E_n' = \frac{K_n}{2j}\cdot\sinh\left(n\frac{\pi}{p\tau}y'\right)\cdot\left[e^{j\left(s\omega t+n\frac{\pi}{p\tau}x'\right)} - e^{j\left(s\omega t-n\frac{\pi}{p\tau}x'\right)}\right]. \qquad (24)$$

The stator linear current density $A_{st}'^{(n)}$ (the n'th harmonic) induced by this field is in accordance with Eqs. 6, 3 and 24

$$A_{st}'^{(n)} = \frac{1}{js\omega\mu_0}\cdot\frac{\partial E'}{\partial y'}_{(y'=0)} = \frac{-K_n}{2s\omega\mu_0}\cdot n\frac{\pi}{p\tau}\cdot\left[e^{j\left(s\omega t+n\frac{\pi}{p\tau}x'\right)} - e^{j\left(s\omega t-n\frac{\pi}{p\tau}x'\right)}\right]. \qquad (25)$$

The two terms of the last expression represent two waves, one advancing the other receding with respect to the rotor, their respective velocities being

$$\frac{dx'}{dt} = \pm\frac{s\omega}{n\dfrac{\pi}{p\tau}} = \pm s\cdot\frac{p}{n}\cdot v_s. \qquad (26)$$

Substituting the value of x' from Eq. 10 into Eq. 25, we obtain the value of the stator linear current density $\mathbf{A}_{st}^{(n)}$ in the stator-fixed coordinate system

$$A_{st}^{(n)} = \frac{-K_n}{2s\omega\mu_0}\cdot n\frac{\pi}{p\tau}\cdot\left\{e^{jn\frac{\pi}{p\tau}x}\cdot e^{j\left[s\left(1+\frac{n}{p}\right)-\frac{n}{p}\right]\omega t} - e^{-jn\frac{\pi}{p\tau}x}\cdot e^{j\left[s\left(1-\frac{n}{p}\right)+\frac{n}{p}\right]}\right\}. \qquad (27)$$

As $\frac{\pi}{p\tau}d$ is normally very small, we deduce from Eq. 23 that the coefficient K_n diminishes as $1/n^2$, the higher harmonics decreasing much faster. The various harmonics $\mathbf{A}_{st}^{(n)}$ will therefore be approximately proportional to $1/n$ while those having $n \gg 1$ will not be felt at all. For $p=1$, the stator of the faulty machine will carry the following additional currents

$$\begin{aligned} I_1 &= \mathbf{I}e^{j\omega t} - \mathbf{I}e^{j(2s-1)\omega t} \\ I_3 &= \tfrac{1}{3}\mathbf{I}e^{j(3-2s)\omega t} - \tfrac{1}{3}\mathbf{I}'e^{j(4s-3)\omega t} \\ I_5 &= \tfrac{1}{5}\mathbf{I}e^{j(5-4s)\omega t} - \tfrac{1}{5}\mathbf{I}e^{j(6s-5)\omega t'}. \\ &\vdots \end{aligned} \qquad (28)$$

Only the first term of the first harmonic I_1 is of the same frequency as the supply source while all others, their frequencies being different, will cause the usual disturbances associated with such currents.

When $p = 2m$ (even number) no disturbances will occur in the machine's normal performance, as according to Eq. 36 (see Appendix 2) no hypothetical generators should be inserted in the damaged rotor. From the physical point of view, the explanation is that each part of the broken rotor is $p\tau = 2m\tau$ wide and comprises an integral number of wavelengths. As we assumed the end rings to be perfect conductors, no disturbances are caused by interrupting one or both of them diametrically. The currents flowing in the squirrel bars find closed paths in each separate part of the broken rings.

6. END RINGS BROKEN AT VARIOUS PLACES

In the case of squirrel-cage rings both open-circuited at two points not exactly $p\tau$ apart, a line of reasoning similar to that adopted in the preceding sections should be followed. Hypothetical generators, equal in frequencies and voltages but different in phase should be inserted at the spots of breakdown. The phase difference will be dictated by the distance between the open circuits. The generator voltage is to be found by Kirchhoff's law, which postulates the sum of all currents in each separate part of the broken squirrel-cage to be zero. A similar pattern is to be followed in case of a double open-circuit in one ring only. Two hypothetical generators are all that is required, and the peripheral electric field E_z exists in the broken ring only.

In case of a double open-circuit in one ring or in both of them $k\tau$ apart, k being an even integer, no additional currents will be induced in the stator. No deviation in performance will be shown by such a motor compared with a normal machine.

In case of a single open-circuit in one or both end-rings, the currents leaving the cage-bars will follow a path in the end rings, different from the usual one. In all above calculations we omitted the "end effect" altogether so that no disturbances will be observed as a result of these calculations.

7. THE TORQUE/SLIP CHARACTERISTIC

The additional currents of various frequencies (see Eq. 28) are associated with harmonic torques identical in general form with the fundamental torque/slip curve, but with different synchronous speeds. Whereas the fundamental torque is zero for $s = 0$, the harmonic torques will be zero for $s = \frac{1}{2}$; $s = \frac{3}{2}$; $s = \frac{3}{4}$, etc. The resultant torque/slip curve is obtained by superposition of the additional torques on the fundamental one. Consequently, it will show the well-known "saddle effect." If the amplitude of the parasitic torque is appreciable, it may cause the motor to crawl at an abnormally low speed.

8. PHYSICAL INTERPRETATION

In the normal machine the fundamental magnetic field moves forward at the velocity v_s with respect to the stator, and $s \cdot v_s$ with respect to the rotor. This field induces in the cage-bars axial currents which constitute a wave advancing at a velocity v_s with respect to the stator, that is, synchronous with the advancing wave of the linear current density of the stator. The axial bar-currents are closed in the end rings on both sides of the rotor, so that a wave advancing at the same velocity occurs in the end rings as well. In case of double open-circuited end rings, the advancing wave, when arriving at the points of interruption (at which the rings are broken), causes a receding "echo-wave" in both rings and bars. The frequency of this echo-wave is the same as that of advancing wave, *viz.* sf. Spatially the echo consists of harmonics 1, 3, 5 $\cdots$ the fundamental length of which is equal to the circumference of the rotor. All these harmonics move therefore at different velocities with regard to the rotor and consequently induce different frequencies in the stator. The amplitude of the echo-wave (and, consequently, that of the stator's parasitic currents) is such that the total current of each separate part of the broken cage is zero in accordance with Kirchhoff's first law.

The above discussion shows that every asymmetry in the rotor's cage whether it be an actual open circuit or just a local increase in the resistance of the rings or bars will cause an echo wave with all its consequences. The deviation from normal performance is dictated by the degree of asymmetry.

Acknowledgment

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LIST OF SYMBOLS

d—length of air gap (m)
δ—thickness of rotor's conductive layer (m)
σ—rotor's layer specific conductivity
H—intensity of magnetic field (amp/m)
E—intensity of electric field (volt/m)
μ_0—permeability of free space
A_{st}—stator's linear current density (amp/m)
A_r—rotor's linear current density (amp/m)
τ—pole pitch (m)
p—number of pole pairs
q—number of slots per pole and phase
w—number of conductors in each slot
v—rotor's peripheral speed (m/sec)
v_s—the synchronous speed (m/sec)
s—slip
ω—angular frequency.

APPENDIX 1

Equations 3, 6, 8 and 12 yield

$$\frac{1}{j\omega\mu_0}\cdot\frac{\pi}{\tau}(K^+ - K^-) = A_m. \tag{29}$$

As is well known, the frequency in the rotor-fixed rotating coordinate system is $s\cdot f$ and $\mathbf{E}' = s\cdot\mathbf{E}$. Equation 3 in this system would therefore take the form

$$\mathbf{H}_y = \frac{-1}{js\omega\mu_0}\cdot\frac{s\mathbf{E}}{sy}. \tag{3a}$$

Equations 3*a*, 7, 11 and 12 lead to

$$\frac{-1}{j\omega\mu_0}\cdot\frac{\pi}{\tau}\left[K^+\cdot e^{\frac{\pi}{\tau}d} - K^-\cdot e^{-\frac{\pi}{\tau}d}\right] = \sigma\cdot\delta\cdot s\left[K^+ e^{\frac{\pi}{\tau}d} + K^- e^{-\frac{\pi}{\tau}d}\right]. \tag{30}$$

Hence

$$K^+ = A_m\cdot j\omega\mu_0\frac{\tau}{\pi}\cdot\frac{\left(\sigma\delta js\omega\mu_0\frac{\tau}{\pi} - 1\right)\frac{1}{2}e^{-\frac{\pi}{\tau}d}}{\sinh\frac{\pi}{\tau}d + \sigma\delta js\omega\mu_0\frac{\tau}{\pi}\cdot\cosh\frac{\pi}{\tau}d}, \tag{31}$$

$$K^- = -A_m\cdot j\omega\mu_0\frac{\tau}{\pi}\cdot\frac{\left(\sigma\delta js\omega\mu_0\frac{\tau}{\pi} + 1\right)\frac{1}{2}e^{\frac{\pi}{\tau}d}}{\sinh\frac{\pi}{\tau}d + \sigma\delta js\omega\mu_0\frac{\tau}{\pi}\cosh\frac{\pi}{\tau}d}. \tag{32}$$

APPENDIX 2

Equations 3, 7 and 22 yield the linear current density of the rotor with four hypothetical generators

$$\mathbf{A}_r = \mathbf{H}'_{x(y'-d)} = \frac{-1}{js\omega\mu_0}\cdot\frac{\partial\mathbf{E}'}{\partial y'}_{(y'-d)} = \sum_{n=1}^{\infty}\frac{-K_n}{js\omega\mu_0}\cdot n\frac{\pi}{p\tau}\cdot\cosh\left(n\frac{\pi}{\tau}d\right)\sinh\left(n\frac{\pi}{p\tau}x'\right);$$

$$n = 1, 3, 5, \cdots. \qquad (33)$$

In a similar way one may obtain from Eqs. 3, 7 and 13 the rotor's linear current density in the normal machine (which we shall denote by $\mathbf{A}'_{r\ \mathrm{normal}}$)

$$\mathbf{A}'_{r\ \mathrm{normal}} = \mathbf{H}_{x(y'-d)} = \frac{-1}{js\omega\mu_0}\cdot\frac{\partial\mathbf{E}'}{\partial y'}_{(y'-d)} = A_m\cdot\frac{\sigma\delta js\omega\mu_0\frac{\tau}{\pi}}{\sinh\frac{\pi}{\tau}d + \sigma\delta js\omega\mu_0\frac{\tau}{\pi}\cdot\cosh\frac{\pi}{\tau}d}\cdot e^{-j\frac{\pi}{\tau}x'}. \qquad (34)$$

(It should be borne in mind that $\mathbf{E}'$ equals s times $\mathbf{E}$.) Because of the open circuits at $x' = 0$ and $x' = p\tau$ one should postulate, in accordance with Kirchhoff's law,

$$\int_0^{p\tau}(\mathbf{A}'_r + \mathbf{A}'_{r\ \mathrm{normal}})dx^i = 0. \qquad (35)$$

Substituting (23), (33) and (34) into the last equation, one has

$$A_m\cdot\frac{\sigma\delta js\omega\mu_0\frac{\tau}{\pi}}{\sinh\frac{\pi}{\tau}d + \sigma\delta js\omega\mu_0\frac{\tau}{\pi}\cdot\cosh\frac{\pi}{\tau}d}\cdot\frac{e^{-jp\pi}-1}{-j\frac{\pi}{\tau}}$$

$$+\,\mathbf{U}\cdot\frac{4}{l\pi js\omega\mu_0}\cdot\sum_{n=1}^{\infty}\frac{\frac{1}{n}}{\dfrac{\tanh\left(n\frac{\pi}{p\tau}d\right)}{n\frac{\pi}{p\tau}d}+\dfrac{1}{js\omega\mu_0\sigma\delta}}\cdot\frac{\cos(n\pi)-1}{n\frac{\pi}{p\tau}} = 0. \qquad (36)$$

Hence when $p = 2m$ (an even number), $e^{-jp\pi} = 1$ and $\mathbf{U} = 0$; and when $p = 2m + 1$ (an odd number)

$$\mathbf{U} = A_m\frac{s\omega\mu_0\sigma\delta}{\frac{\pi}{\tau}\cdot\sinh\frac{\pi}{\tau}d + js\omega\mu_0\sigma\delta\cdot\cosh\frac{\pi}{\tau}d}\cdot\frac{l\tau}{4}\cdot\frac{1}{\displaystyle\sum_{n=1}^{\infty}\frac{\sigma\cdot\delta}{n^2\frac{\pi}{p\tau}+js\omega\mu_0\sigma\delta\cdot\tanh\left(n\frac{\pi}{p\tau}d\right)}}. \qquad (37)$$

Speed of Light Used in Surveying.—A precise distance measuring instrument with an accurate operating range of up to 50 miles under excellent visibility conditions is undergoing rigid tests at the Corps of Engineers' Research and Development Laboratories, Fort Belvoir, Virginia.

The "geodimeter," an electronic-optical device with which measurements can be made by using a fundamental constant—the velocity of light—is being carefully evaluated by the Laboratories for use in military surveying operations.

Invented by a Swedish geodesist, Dr. Erik Bergstrand, it is designed primarily for the determination of geodetic distances, such as precise lines used in triangulation, but it can also be used under special conditions for surveying by trilateration methods.

Distance measurements are obtained by determining indirectly the time interval for a light beam to travel from the geodimeter to a distant plane mirror and return to the instrument. With the velocity of light already known, distances can be readily computed.

Some preliminary tests on the instrument have already been accomplished by the Laboratories. Measurements were made over special short lines established in cooperation with the U. S. Coast and Geodetic Survey. More rigid procedures were added than normally considered necessary for first-order base line measurements. These resulted in a probable error of lines of about one part in 1,500,000. Test lines used were short. Since errors are largely constant in short lines and are not proportional to distance, it is believed the accuracies would improve considerably with an increase in the length of the base line.

Two basic units compose the geodimeter, measuring and light conductor units. The measuring unit contains the necessary electronic equipment while the light conductor unit consists of a continuously variable light path which has been precisely determined by calibration measurements in the laboratory and two spherical mirrors approximately 12 inches in diameter with necessary optics to project and receive the light beam.

The plane mirror, used at the opposite end of the base line to return the projected light beam to the geodimeter, is equipped with a collimated telescope and vertical and horizontal adjustment mechanisms for precise pointing and plumbing.

Because of the critical requirement for pointing the plane mirror, the Laboratories are investigating the use of retrodirective mirrors and prisms as a replacement. The pointing of this type target is not critical and a rigid support is not required.

Distance measurements can normally be made in two to three hours using a procedure to obtain approximately 16 independent measurements (8 each on the light conductor unit and on the base line). The required computations can be accomplished in some 30 minutes.

Tests have indicated that the geodimeter will prove invaluable as a precise measuring tool for checking other types of distance measuring equipment, particularly of the radar type where terrain and meterological effects are so critical and not too well understood at the present time.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS*

FIRE ENDURANCE STUDIES ON STEEL-JOIST FLOORS

The National Bureau of Standards has recently carried out a research program on the fire resistance of open-web steel-joist floors—a floor type widely used in office and apartment buildings. Conducted by J. V. Ryan and E. W. Bender of the NBS fire protection laboratories, the studies involved a total of 18 fire tests, two of an exploratory nature and the remaining 16 on specimens larger than those usually required for tests of this type. The tests were conducted according to the recommendations of the Standard Test Methods developed by the American Society for Testing Materials.

Floors, walls, partitions and columns in a building provide nearly all of its fire resistance. In general, floors are more important than the other components because they provide natural barriers to the fire's usual upward progress. In many of our modern buildings the vertical dimension is the greatest, and therefore fire resistance in that direction is extremely important.

Ordinarily, the fire resistances of floors are limited either by failure to support the applied load or by a predetermined rise of temperature on the top surface when the fire is below the floor. The fire resistance requirements in building codes refer to the results of fire tests conducted in accordance with standard methods. Laboratory tests as well as actual fires in structures have shown that unprotected steel has very low strength at the temperatures that are soon reached in such fires. Thus, the load-bearing capacity of a combination of a thin concrete slab on open-web steel joists would be short-lived in a fire and its fire endurance correspondingly short. However, the fire resistance may be increased by protecting the joists with some type of ceiling, such as lightweight plaster on gypsum lath.

When exposed to fire, gypsum calcines or loses its combined water. This change is accompanied by shrinkage, cracks, decrease in strength, and eventual breakage of plaster and lath. As the cracking of plaster and lath progresses, the areas into which the ceiling is subdivided by the cracks become smaller and smaller until some parts are loosened. As these unsupported areas of lath and plaster fall, the joists are exposed to the flames and soon lose their strength. This results in load failure. Up to a limit, the fire endurance may be extended by increasing the amount of plaster applied, thus lengthening the time required for the gypsum to calcine. However, after calcination, the gypsum still serves as a shield to protect the joists from radiant energy and from direct contact with the flames. Therefore, any means of keeping the lath and plaster in place following calcination will contribute to greater fire resistance.

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* Communicated by the Director.

In the studies carried out at the Bureau, specimens were constructed according to regular building practices. Floor main members were assembled from open web steel joists upon which were cast concrete slabs. To the bottom chords of the joists were attached steel furring channels and lightweight ceilings of gypsum-perlite plaster on perforated gypsum lath. Various methods of supporting the ceilings were used, and in some of the tests one of two types of additional reinforcement was included. The supporting systems consisted of differently formed wire and sheet metal clips by which the gypsum lath was attached to the furring channels. The clips were specially designed for easy and rapid construction. Additional reinforcements were either straight wires or wire mesh of 1-in. hexagonal openings ("chicken wire"), secured below the lath before application of the plaster. The plaster was applied in various thicknesses from ½ to 1¼ in.

The tests were conducted in furnaces specially designed for fire-testing floors and roofs. Two tests were made in a small furnace which would take a floor 9 ft. by 4 ft. 4 in., and the remaining tests were made in a large furnace which would take a floor 18 ft. by 13 ft. 6 in. Each furnace is in the form of a box open at the top, with gas burners along the sides. The test floor closes the open top, and the underside of the specimen is exposed to the furnace flames. A number of thermocouples are placed inside the furnace to determine the internal temperature, which is varied from 1000 to 2300° F, for various periods of time according to the procedures followed in the Standard Test Method. Other thermocouples on the floor surface and on the joists measure the temperatures of these members during the test. In addition, the specimens are loaded on the top by hydraulic jacks through a load-distributing mechanism, and a system of wires attached to the floor and passed over pulleys to scales provides a means for measuring the floor and beam deflections.

Each test was continued to one of the end-points specified by the Standard Test Method. These end-points occurred when (1) the floor no longer sustained the test load, (2) cracks or openings developed, allowing the passage of flames or gas hot enough to ignite cotton waste, (3) the average temperature of the unexposed floor—measured at five or more points—was 250° F. above the initial temperature, or (4) the temperature as measured by one thermocouple on the unexposed surface was 325° F. above the initial temperature. Although not required by the ASTM Standard Test Method, additional data were obtained relative to the following criteria: (5) the times at which the main steel structural members attained average temperatures of 925° and 1000° F. at one level, and (6) the time at which a main structural steel member attained a temperature of 1200° F. at any one point. In the interest of consistency between individual tests, criterion (1) was taken arbitrarily to be indicated by a 3-in. maximum deflection.

Results of the tests indicate that floor-ceiling assemblies of this type of construction should provide fire resistance from 1 hr. to more than 4 hr.—a range adequate to cover building code requirements. Increased plaster thickness up to 1 in. is accompanied by an increased time of fire resistance, to a maximum of 1¾ hr. before failure occurs. More than 1 in. of plaster, however, gives practically no additional fire protection. On the other hand, use of additional reinforcement in the ceilings increases the fire resistance time to 3¼ hr. with diagonal wires, and to 4½ hr. with chicken wire. The plaster in these reinforced ceilings was 1 in. or less in thickness.

NOTE: For further technical information, see "Fire Endurance of Open-Web Steel-Joist Floors with Concrete Slabs and Gypsum Ceilings," NBS Building Materials and Structures Report 141, available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at a cost of 20 cents.

RADIATION BALANCE

A radiation-balance microcalorimeter recently developed by Dr. W. B. Mann of the National Bureau of Standards precisely determines the emission rate of low-activity radioactive sources. The instrument does this by measuring the minute amounts of heat energy which accompany radioactive emission. The device is extremely compact and requires a relatively short time to complete a determination. It can be used to determine the intensity of a single source or to compare two sources of nearly equivalent energy emission.

A primary function of the National Bureau of Standards is the custody and maintenance of the national standards of physical measurement to meet the needs of science and industry. The Bureau's first standard of radioactivity was brought to this country by Marie Curie in 1913. Subsequently two Hönigschmid radium standards were acquired to calibrate and compare all of the radium sources produced and sold in this country. With the development of atomic energy and the tremendously increased use of radioisotopes, the demand for NBS certification of radioactive sources increased appreciably. To accommodate this new work, the radiation balance was developed and investigated as a possible supplement to existing instruments. It is capable of rapid, accurate determinations, and is expected to aid materially in the certification work.

A calorimeter embodying the principles used in the NBS radiation balance was first described by H. L. Callendar in 1910. With this calorimeter, which he called a radio-balance, Callendar made measurements of solar radiation and also carried out a somewhat preliminary measurement of the energy emitted in unit time from a sealed source of radon. Since that time, apart from a determination of the Stefan-Boltzmann radiation constant by Hoare in the early 1930's, no other reference to the radio-balance has occurred in the scientific literature.

For measurement of radioactive emission a cup form of the radio balance was designed at NBS. This instrument consists essentially of two cups, the temperatures of which are balanced against each other by means of two thermopiles arranged around the equator of each cup and connected in opposition through a sensitive galvanometer. Thus, when there is no difference in temperature between the cups, there will be no deflection of the galvanometer.

A junction of two dissimilar metals, known as a Peltier junction, is soldered to the bottom of each cup. When an electric current is passed through a Peltier junction, heat is either absorbed or generated depending on the direction of the current.

The two junctions are connected in series in such a way that when a current is passed through them one junction cools and the other heats. A radioactive source is placed in cup A, and a current is passed through the junctions in a direction such that Peltier cooling occurs in the junction below A and Peltier heating in the junction below cup B. The current can be adjusted (provided that the source of radioactivity has an energy emission below a certain calculable maximum value) so as partially to balance the energy emission in A with Peltier cooling. With the addition of Peltier heating in B, it is possible to achieve a temperature balance between A and B.

When this balance is achieved, there is normally only a small residual galvanometer deflection. Since the temperature of cup A is now very nearly equal to that of cup B, the heat losses from the cups, which occur chiefly along the thermopile leads, are essentially equal and compensatory.

This technique may also be used to compare two radioactive sources and can in fact be used to compare two nearly equal sources without the use of Peltier cooling or heating at all. When the energy emission value of a single source is required, it is desirable to use a similar dummy source in the second cup in order that the thermal conditions in the two cups may be essentially the same.

To measure absolute values of radioactive emission, the radiation balance is first calibrated by determining the magnitude of the Peltier effect in the junctions soldered to the bottom of each cup. For this purpose, two small accurately calibrated resistance coils (R and r) were wound on platinum wire to simulate the thermal conductivity of the platinum-iridium needles. The coils are connected in series with the Peltier junctions, so that the same current flows through the coils and the junctions. One coil is then inserted into each cup of the radiation balance, the current is adjusted in magnitude and direction to obtain balance, and the value of the current is determined.

When the galvanometer balance is achieved, a condition exists such that

$$i^2(R-r)=2Pi,$$

where i is the current flowing through the coils and the junctions, and R and r designate the resistances of the two coils. The Peltier effect P can be determined directly from this equation.

For the absolute measurement of the energy emission of a radioactive material, the source to be measured is placed in one cup, and a dummy is placed in the other. When the Peltier current has been adjusted to give a thermopile galvanometer balance, the difference in the energy emission from the sources is equal to the product of twice the current and the Peltier coefficient. Since the energy emission from the dummy is zero, the energy difference is equal in value to the emission of the radioactive source.

A number of radiation balances have now been constructed at NBS, and their application to the measurement of the energy emission from radium has been studied. One of these instruments, with cups of gold, has been used to compare the U. S. and British primary radium standards with the Canadian national radium standard. With this radiation balance, the standard deviation of the results was only 0.13 percent.

The Bureau's radiation balances also have been used to measure the energy output of commercial radium preparations. The instruments are currently being applied to the determination of the branching ratio in the decay of polonium-210 and to the preparation of NBS tritium standards.

THE FRANKLIN INSTITUTE

MINUTES OF THE ANNUAL MEETING
January 19, 1955

The Annual Meeting of The Franklin Institute was held on Wednesday, January 19, 1955, in the Lecture Hall. S. Wyman Rolph, President, called the meeting to order at 8:15 P.M. Approximately 250 members and guests were in attendance.

The President stated that the Minutes of the November Stated Meeting were printed in the November JOURNAL and asked if there were any corrections, additions or changes. None being offered, they were approved as submitted. Minutes of the December Stated Meeting will be printed in the January JOURNAL and will be submitted for approval at the next Stated Meeting.

The President then called for the report of the Tellers appointed in accordance with the By-Laws to count the votes for the eight Managers to be elected. Joseph S. Hepburn, Chairman, reported that a total of 988 ballots were cast, of which 959 were legal and 29 defective, and that the nominees received votes as follows:

Henry B. Bryans	954	W. H. Fulweiler	949
Francis J. Chesterman	953	Gaylord P. Harnwell	954
James Creese	955	Harold LeDuc	949
Rupen Eksergian	949	Emery W. Loomis	950

The President declared that the above members were thereby elected Managers of the Institute for a term of three years. He thanked Joseph S. Hepburn, Howard Stoertz, and Walter Pertuch (who served for George S. Crampton, who was ill) for their services.

The President announced that the Annual Report of the Board of Managers will be presented at a meeting in the spring after receipt of the Auditor's report.

The Secretary reported that elections to membership, recorded since November 30th, resulted in a net gain in the following classes of membership:

Associate	4
Student	2

and a total membership, including individuals with Library privileges under Company membership, of 6,828 as of December 31, 1954.

The Secretary read the following report of the Trustees of the Elliott Cresson Fund:

ELLIOTT CRESSON MEDAL FUND

Report of the Trustees to The Franklin Institute
January 19, 1955

The deed of gift under which Elliott Cresson, in 1848, gave $1,000.00 to two trustees, the income of which was to furnish medals to be awarded by The Franklin Institute, provided that the trustees should present to the Annual Meeting of the Institute, in January, a report showing the principal of the fund and its income and expenses during the preceding year.

Principal of the Fund (representing the original $1000 plus transfers thereto from Unexpended Income and profit from disposition of investments)		$4,304.73
Invested as follows:		
$4000 U. S. Treasury 2½% bonds due 6/15/1962–67 at book value	$4,118.47	
Cash in Western Savings Fund Society	186.26	
	$4,304.73	

Income of the Fund for 1954		
Interest on bonds (less amortization)	$ 126.29	
Interest on bank balance	3.56	$ 129.85
Expenses		
Insurance of medal dies		6.88
Unexpended Income for the year		$ 122.97
Unexpended Income at January 1, 1954		2,145.49
		$2,268.46
Invested as follows:		
$2000 U. S. Treasury 2½% bonds due 6/15/1962–67 at book value	$2,059.54	
Cash in Fidelity-Philadelphia Trust Company	208.92	
	$2,268.46	

/s/ Henry B. Allen
HENRY B. ALLEN
/s/ John Frazer
JOHN FRAZER
Trustees

The President introduced Dr. L. K. Sillcox who is Honorary Vice-Chairman of the Board of The New York Air Brake Company, and recipient of gold medals from the Institution of Locomotive Engineers of London and from the American Society of Mechanical Engineers. Dr. Sillcox's interesting talk—"Fuels of the Future"—was followed by a lively question and answer period. The lecture will be published in the March issue of the JOURNAL.

The meeting adjourned at 9:20 with a rising vote of thanks to Dr. Sillcox.

HENRY B. ALLEN
Secretary

MEMBERSHIP

ACTIVE MEMBERS ELECTED BY THE BOARD OF MANAGERS

January 19, 1955

ACTIVE NON-RESIDENT LIFE

Walton Clark, III

ACTIVE FAMILY

E. Stanley Bowers, Jr.
Francis J. Cubberley
Otto T. Mallery
Carrell J. Stover
Philip S. Vincent

ACTIVE

Howard Muir Ambler
J. Neill Armstrong
John L. Asher
F. Bruce Baldwin, Jr.
Charles P. Barth
Francis J. Borowsky
Grant H. Brewin
A. M. Callanan
Watson T. Chesterman
Harriet Corbett
A. Reynolds Crane
Max Frager
Loren F. Jones
Edward F. Kerns
Benjamin Larzelere
Theodore Levenson
Thomas H. MacCauley
Thomas F. McLaughlin, Jr.
Kathryn Coleman Persing
George S. Saulnier
J. Paul Sticht
R. W. Struse
Frederick Ullberg, Jr.
Preston Dudley Wagar
C. H. Whittum
Robert E. Young

NON-RESIDENT

Paul A. Mulcey

NECROLOGY

Maxwell Alpern '36
Raymond Foss Bacon '15
Thomas Curran '46
Leonard Gutekunst '43
Irene B. Halstead '36
J. Edward Patterson '36

JOURNAL OF THE FRANKLIN INSTITUTE

The following papers will appear in this JOURNAL within the next few months:

ABRAMOVITZ, STANLEY: Theory for a Slider Bearing with a Convex Pad Surface, Side Leakage Neglected.
MINORSKY, N.: On Asynchronous Action.
MALIC, DRAGOMIR: The Equation of Polytropic Process of Real Gases.
PAI, S. I.: On the Stability of Parallel Flows with Respect to Periodic Disturbances.
SILLCOX, L. K.: Fuels of the Future.
FALES, ELISHA N.: A New Laboratory Technique for Investigation of the Origin of Fluid Turbulence.
COULSON, THOMAS: Some Prominent Members of The Franklin Institute. No. 2, Joseph Saxton.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A. M. until 5 P. M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; 2 P. M. until 10 P. M. on Wednesdays.

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TO MEMBERS AND THOSE WHO KNOW THE FRANKLIN INSTITUTE

All of us associated with The Franklin Institute are gratified by the support given by its benefactors in the past. Without their generosity our privately endowed Institute would have been unable to serve industry, the professions, and the public as it has and should.

There is still a continuing and pressing need of contributions and bequests—both for general and specific endowment, and of income to be judiciously used. Your response will be most earnestly appreciated.

Checks should be made payable to The Franklin Institute, and sent to The Franklin Institute, Benjamin Franklin Parkway at 20th Street, Philadelphia 3, Pennsylvania.

Where property is transferred, title should be in the name of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts.

We shall be glad to supply any additional information regarding gifts and memorials. Please write to the above address, attention of the Endowment Department.

NOTES FROM THE FRANKLIN INSTITUTE MUSEUM

A. C. CARLTON, DIRECTOR

THE NICKELODEON

When Thomas Alva Edison developed the successful method of showing motion pictures, he was uncommonly cautious in his manner of commercializing the invention. The film recording a picture was packed in a cabinet and could only be seen by a single pair of eyes at a time. This peep-show method of viewing the pictures was not long to endure. Other men perceived what Edison did not realize, that he had uncovered the means of providing entertainment for crowds, and they strove to perfect the methods of projecting the pictures on large screens where they could be seen by large audiences.

A number of ingenious men worked upon the minor problems that were encountered before the projecting apparatus was perfected. Finally, when all was ready, the suitable halls for the display of the pictures were lacking. Enterprising men who had the foresight to perceive the possibilities of this new form of entertainment did not wait until halls were built. They acquired the apparatus necessary for projection and showed the pictures in tents or any other place they could find or could convert into a suitable space for an audience.

Eventually, the motion picture theatre was evolved. The earliest of these, the popular Nickelodeons, were a far cry from the palatial theatres we enjoy today, but they represent a period of American life that is a joyful memory to those of today's older generation.

The technical development of the motion picture has close association with members of The Franklin Institute. It is, therefore, appropriate that the Museum should display some feature that is characteristic of the rise and progress of this industry which has shown phenomenal advancement. No happier choice could have been made than to realize the ambitious proposal to reproduce a specimen of the Nickelodeon, which saw the industry launched upon a substantial foundation.

Fortunately, the Museum was able to secure the co-operation of Mr. William Goldman, a prominent figure in the exhibition field and himself a pioneer in the industry. Through Mr. Goldman's generosity the Nickelodeon has been constructed and through his enthusiasm and vision the reconstruction has been achieved with fidelity to detail.

All the familiar furnishings and fittings have been assembled with care to make the interior as nearly authentic as possible, and strictly in keeping with the spirit of the time. The curtain depicts the arrival of Benjamin Franklin in Philadelphia, and is embellished with advertisements of local firms that were already established in the city at the opening of the century.

The exterior is a faithful reproduction of a corner of the city in which a Nickelodeon would be built. A colored mural reproduces a street scene in the early 1900's, which is the setting for the Nickelodeon's front, with its ticket office and other characteristic features.

In order that the spirit of the period may be recaptured in its entirety, the pictures to be shown will be selected from among those that were "featured" in the early days of the industry. This will enable older visitors to recall memories of the screen favorites of their youth, and it will enable younger visitors to witness the performances of those famous players who are today only names—but familiar names.

From the interest aroused in passers-by during the preparation of the Nickelodeon and the impatience at the pains being taken which hindered rapid construction, there is no doubt that this "exhibit" in the Museum is destined to be highly popular.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

NICOL H. SMITH, DIRECTOR

A SYSTEM FOR FACSIMILE TRANSMISSION OF DOCUMENTS

EDWARD A. FASKO

As large banking organizations have expanded their services, a problem has developed which in some cases is becoming acute. It is possible for a check drawn against any one of the bank's numerous accounts to be presented for payment at any of the branches. At each branch, the tellers must have access to a file of specimen signatures for comparison purposes. These files are large and costly to install and maintain, particularly when a large proportion of the accounts are commercial.

The Franklin Institute Laboratories recently completed a study of possible solutions for this problem under the sponsorship of one of Philadelphia's largest banks. Officers of the bank desired to establish a single file of signature cards at the central office. This would require the use of a communications system which would allow any signature to be displayed in any outlying branch at the request of a teller at that branch. That the system would also transmit facsimiles of larger sized documents, such as letter or ledger sheets was considered a desirable feature. However, this was not a primary requirement.

The construction of a wholly new, specially designed facility was not considered to be economically justifiable. Rather, it was intended that the system be commercially available or assembled from available components. The Franklin Institute Laboratories studied the system requirements in terms of the frequency of requests for signature verification, the time which could be allotted to the verification, the desirable characteristics of the remote display, and space requirements.

Commercially available data-transmission systems such as industrial television and facsimile systems were compared in light of the preceding requirements. Their speeds of transmission, convenience of use, required bandwidths and type of transmission facilities such as coaxial cable or microwave link, and costs of installation, operation and maintenance were studied. The Federal Communications Commission regulations were examined and the economics of various leased links were compared.

The outcome of this work is a pilot communications system in use by the bank. This installation is a facsimile system linking the bank's central office and two of its closer branches. It will be operated for a sufficient length of time to validate the conclusions of the study, and to evaluate its advantages in actual use.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

Abstract of **The Effect of 2-Desoxy-D-glucose on Glycolysis and Respiration of Tumor and Normal Tissues.**—GLADYS E. WOODWARD AND MARIE T. HUDSON (*Cancer Research*, **14**, 599–605 (1954)). The glucose analog, 2-desoxy-D-glucose (2DG), has been shown to inhibit the anaerobic and aerobic glycolysis of glucose (glucolysis) by slices of the rat tumors, Flexner-Jobling carcinoma and Walker 256 carcinoma. The anaerobic glucolysis of slices of rat brain and sections of rat diaphragm was also inhibited by 2DG. Brain was about 7.5 times more sensitive to 2DG than was tumor. Diaphragm was intermediate between brain and tumor in sensitivity toward 2DG.

The type of inhibition appeared to be competitive, since inhibition was reversed by increased glucose in the case of tumor and brain.

2DG also inhibited the anaerobic glycolysis of fructose (fructolysis) by tumor tissue slices. Tumor fructolysis was at least 50 times more sensitive to 2DG than was tumor glucolysis. The anaerobic fructolysis of liver was also inhibited by 2DG, but was about 100 times less sensitive to 2DG than was tumor fructolysis.

2DG did not significantly inhibit the endogenous respiration in any of the tissues studied. Oxidation of glucose by brain tissue slices was inhibited only by a very high proportion of 2DG to glucose, while oxidation of fructose was about 100 times more sensitive to 2DG than was oxidation of glucose.

The possibility is discussed that 2DG *in vivo* might have a selective inhibitory effect on tumor metabolism.

ONE HUNDRED YEARS AGO IN THE *JOURNAL*

At a time when the Navy's largest vessel—the *U. S. S. Forrestal*—is in its final stages of outfitting, it is interesting to look back to the kind of Navy this country had a century ago. It is described in the following condensation of an original contribution that appeared on pp. 126–129 of the February 1855 issue of the JOURNAL.

Steam Navy of the United States

At a time like the present, when the United States may, at a moment's notice, be brought in contact with some of the naval powers of Europe, we may, with propriety, examine into that branch of our Navy, upon which we must rely in case of such collision. Any fleet that ventures into action without the aid and assistance of steamers will only do so to be defeated, for the ability to take position has always been considered an element of success.

Of steamers, that are already built and in service, we have as follows:

The Mississippi,	side wheel,	1788 tons,	10 guns
" Susquehanna,	"	2436 "	10 "
" Powhattan,	"	2419 "	10 "
" Saranac,	"	1426 "	8 "
" San Jacinto,	propeller,	1426 "	8 "
" Princeton,	"		8 "
" Fulton,	side wheel,		5 "
" Michigan,	"		1 "

In addition to the above, we have a few small craft that might possibly be of use on coast duty, but are unfit for foreign service.

Congress, at its last Session, authorized the construction of six first class war steamers; and at a board of officers, held at Washington, it was decided that they should be sailing ships *with auxiliary screw power;* that the propeller should have two blades, and be arranged so as to hoist out of the water when the vessel was under canvas. As these vessels have two gun decks, and a capacity to carry fifty 8 and 10 inch guns, it became necessary to exercise much caution, so that a proper capacity should be allowed to each department. Thus, 50 guns involve a certain number of men, the number of men regulates the quantity of water, provisions, etc.; and the utmost space that could be allowed to the machinery and coal, was 60 feet in length by the width of the ship under the lower deck, which was 17 feet from face of timbers.

The plans and propositions of the following parties were accepted, and contacts made with them for the machinery, to be made from their own designs, the same being warranted by them for six months after the trial trip. Anderson, Delany & Co., of Richmond, Va., build the machinery for the *Roanoke* and *Colorado*, at Norfolk; Merrick & Sons, of Philadelphia, for the *Wabash*, at Philadelphia; Robert P. Parrott, (West Point Foundry,) for the *Merrimac* at Boston. The machinery for the *Minnesota*, at Washington, is to be built at the Government shops, in the Navy Yard at that place, from designs prepared by Mr. Martin, Engineer-in-Chief of the Navy.

The following are the principal dimensions of these vessels:

Length between perpendiculars,		265 feet	8 inches
" from knight-head to taffrail,		287 "	7 "
Beam, moulded,		50 "	2 "
" outside of plank,		51 "	4 "
Depth of hold to gun deck,		26 "	2 "
" to spar deck,		32 "	7 "
Tonnage,	3200 tons		

They are being built in the most substantial manner, having a live oak frame diagonally plated with iron inside, and white oak keel, keelsons, and plank. Much activity is being used in their construction, and all of them will, no doubt, be launched by the first of October next, and in commission in four months from that date.

The *Niagara*, differing in very many respects from the others, requires special notice. The hull of this vessel is being constructed from the designs and under the immediate supervision of Mr. George Steers, known as the builder of the yacht *America*. She is building at the Brooklyn Navy Yard, and has the following principal dimensions:

Length over all,	345 feet
" on load line,	333 "
Beam outside of plank,	55 "
Depth of hold to spar deck,	31 "
Tonnage,	4800 tons

This vessel is to have but one gun-deck, and will carry 12 guns of the largest size. This reduction of armament, combined with her increased size, allows of a material increase in the space allotted for machinery.

[The speed of the first five vessels was estimated to be 8 knots in fair weather; and that of the *Niagara* about 12 knots.]

In addition to these vessels, the Department are building at Portsmouth, N. H., in place of the line battle ship *Franklin*, condemned, a large screw steamer of 50 guns, but no progress has been made in her machinery.

In addition to all these vessels the Secretary of the Navy proposes to build 6 screw steamers of about 1500 tons. This matter is before Congress, and appropriations for their construction will, no doubt, be made the present Session.

Supposing this to be done, we shall then have 22 steamers, a number, which while it will not compare with the navies of England or France, still, will make a respectable show, and would, no doubt, be heard from in any naval action in which they took a part. B.

PRESENTATION OF DIESEL MANUSCRIPT TO THE FRANKLIN INSTITUTE

November 17, 1954

An original manuscript from the estate of Rudolf Diesel, inventor of the Diesel Engine, was presented to The Franklin Institute by Otto T. Mallery, Chairman of the Interdependence Council on Wednesday, November 17, in the Board Room of The Franklin Institute. The manuscript, an historical document in the field of power production, is in Rudolf Diesel's handwriting and outlines his early ideas in the application of the diesel engine to railroad locomotives. Dr. Eugen Diesel, son of the inventor, in this country as a guest of the State Department and the Interdependence Council, first presented the Diesel manuscript to the Interdependence Council in recognition of its efforts in bringing about a closer understanding among the peoples of all nations, an aim of both himself and his father.

The transcript of the proceedings follows.

* * *

MR. S. WYMAN ROLPH: "Ladies and Gentlemen: As President of The Franklin Institute, I shall just call our little meeting to order. This is a very happy occasion for The Franklin Institute. We welcome you. It is our privilege to hear first this afternoon from Dr. Eugen Diesel, who is the son of the great inventor, Dr. Rudolf Diesel. Dr. Diesel will speak to us and then make a presentation to Mr. Mallery, Chairman of the Interdependence Council. Dr. Diesel."

DR. EUGEN DIESEL: "More than a century ago it became apparent that the steam engine, the mighty source of mechanical power, had a basic defect. It had started an industrial revolution and, by separating countless people from their old homes and crowding them in large factories around the steam power plants, it had also begun an economic and social revolution. Fundamental changes in society appeared in a century ruled by the idea of progress. Great economic and humanitarian hopes were being entertained.

"The steam engine, however, fell short of expectations. The best and largest steam engine was unable to convert into practical use more than 10% of the calories contained in the coal it consumed. Still worse, small engines converted only 2%. Consequently, the richer man who could afford to buy large plants had at his disposal mechanical power at only a fifth of the cost to the artisan or small industrialist. Thus, capitalism developed, with its attendant evils and consequently Socialism began to arise.

"During these days, when my father, Rudolf Diesel, was a student, he became keenly aware of the technical deficiency of the steam engine and of the unfortunate social consequences of its application, especially in big factories. At the age of 22, he was inspired to plan a caloric engine that would be far more economic than the steam engine. He dreamed of a small engine which might show at least the same economy as the large one. He wished also to transfer combustion into the cylinder, thus avoiding the necessity for a heavy and unpracticable boiler.

"By 1897, Rudolf Diesel had succeeded in his ambition. He had constructed a rational heat engine as he called it three times more economical than the steam engine. He nourished high hopes that everywhere this new engine would replace the old and that soon even automobiles and locomotives would be driven by the new motor. He lived to see many of these hopes fulfilled. He saw his engine used in ever growing numbers of power houses, ships and ocean liners.

"In some respects, however, he was deeply disappointed. Some industrialists who were following the Diesel Line were not keen on either the Diesel automobile or on the Diesel locomotive, especially as the early models were rather heavy, complicated and expensive prime movers. To force fuel into the cylinders required the application of compressed air and this meant using a costly and heavy air compressor. Largely through the efforts of Robert Bosch this difficulty was solved after 1924 by replacing the air compressors by hydraulic injection pumps and so high speed Diesel engines became available for trucks and, indeed, for all kinds of other purposes.

"Rudolf Diesel had himself foreseen this development at a time when the compressorless engine still seemed utopian. He wished to see automobiles and trucks driven by Diesel engines and when most industrialists held back on this development he himself began to design motors both for trucks and locomotives. He succeeded and in 1912 he built in Switzerland and Germany the first large and powerful Diesel truck and locomotive.

"This manuscript of my father marks the beginning of the universal application of the Diesel engine to various forms of human endeavor. Fifty years after he wrote it the huge American railway network is based upon the engine which he proposed to build. Diesel-powered trucks and cars are on the roads and Diesel-engined ships are on the seas. Even now, engineers everywhere are busily trying to solve the problem of the lightweight Diesel engine, the fulfillment of my father's aim to help all men by providing them with cheap and economic power.

"These plans for smaller engines, now reaching their completion, may revolutionize small business and bring great and hitherto undreamed betterments into every home. A one-horse power Diesel engine, capable of being carried on a man's back, is even now nearing completion; it is expected to do great good in the development of so-called backward regions, in reclaiming swamps and jungles and deserts, and in providing emergency power to counteract the effects of such disasters as dust storms and hurricanes. It is expected to bring air conditioning at a cheap price to every home and to offer to all families the great benefits of large scale economies hitherto reserved to the rich. To do this will increase the awareness of our mutual interdependence to promote the general welfare and to aid in the furtherance of peace.

"The Diesel engine and its development are symbols of interdependence, of world-wide unity, of intellectual and social cooperation among all peoples. This manuscript which I desire to present was a forerunner of progress for it represents a man's dream, and his accomplishment of that dream of solving the problem of his century.

"When, in August of this year, I left Germany for the United States by way of Japan, I recalled that in America the Diesel locomotive was making far greater progress than in any other country of the world. This nation has done more than any other to realize one of my father's favorite ideas. I therefore brought with me a manuscript which my father had written either in 1905 or 1906 containing his first studies of the possibilities of the Diesel locomotive. I hoped I would find an opportunity to present this manuscript to some individual or to some scientific institution as a token of my gratitude to America.

"Here in Philadelphia I have met men and have visited institutions of such a nature. Here in Philadelphia the independence of a great nation was proclaimed. Here, in the 18th century, science and industry, social and political idealism, religion and philosophy have been unified in unique activities. This Philadelphia atmosphere, these unique idealistic and practical activities, underlie and inspire the powers which have shaped America. They must, indeed, dominate the whole world if we are to survive and if our world is to improve. As this world develops into a world of general interdependence it must be shaped and directed by men who represent the good will of mankind.

"I now present this manuscript to Mr. Otto Tod Mallery, a citizen of Philadelphia and chairman of the Interdependence Council, for it was his personality and the declaration of Interdependence sponsored by that Council which brought me to the United States and to Philadelphia. I heartily agree with Mr. Mallery that there is no better place to shelter my father's manuscript than The Franklin Institute, a shrine for all men who venerate the memory of Benjamin Franklin and who cherish scientific and social ideals."

MR. OTTO TOD MALLERY: "Dr. Eugen Diesel, the Interdependence Council gratefully accepts from your hands this historic and unique document of your father, Rudolf Diesel.

"Your father's invention of the Diesel engine has proved once more that a discovery by one is the good fortune of all. His invention has helped to show that the common needs drawing people together are stronger than artificial barriers which keep them apart. Rudolf Diesel set out to make a better world and made a more efficient engine.

"The tragedy of today is that, unlike Rudolf Diesel's dream, the finest scientific minds are being centered too much upon engines of potential destruction. Rudolf Diesel's creative genius developed the intangibles of yesterday into the realities of today. You, his son, are carrying on his vision in your philosophy and writings, and, as a member of the Interdependence Council, are helping to find a more efficient application of the drawing power of common interests between nations.

"Seneca said that we can be thankful for a few acres or a little money, yet for the great intangible benefits of our being we look upon ourselves as under no obligation. Among these benefits are liberty and the pursuit of happiness, which our generation did not create but which it is challenged to preserve. Machines alone do not preserve or advance civilization. Advance depends upon the purpose behind the machine. Man has the capacity to express divine purpose. We honor Rudolf Diesel and all others like him who by invention, skill, philosophy, labor and management have set higher aims for human progress.

"Such aims have been assembled during the last two years by men in 40 nations and embodied in the Declaration of Interdependence, under the sponsorship of the Interdependence Council. The signers of the Declaration are aware that the discoveries in atomic fission require the scrapping of outworn ideas and an increase in the sense of interdependence among peoples. Like the propositions in the Declaration of 1776, those of the Declaration of Interdependence state the needs of its time.

"Here in Philadelphia we pay constant tribute to the memory of Benjamin Franklin and his participation in forming bold new political institutions during the darkest days preceding and after the American Revolution. Like your father, Benjamin Franklin was a social reformer as well as an inventor. Among his inventions is a lamp for lighting streets. Like the Diesel engine, Franklin's lamp was more efficient than its predecessors, so much so that in 1790 the Spanish Government of Louisiana ordered its street lights from Philadelphia. Both the Franklin and Diesel inventions threw a brighter light upon the paths of men. The Franklin Institute keeps such scientific lights burning for the illumination of succeeding generations. As the Honorary Secretary of the Council of the Deutsches Museum, in Munich, an institution parallel to The Franklin Institute, you will appreciate this.

"After research has been completed upon the exact design of Franklin's lamp, a model will be sent to you as a reminder of your visit to Philadelphia. The lamp will also be a testimony to the undaunted quest for clearer light upon the affairs of men.

"And because The Franklin Institute carries on the work and hopes of men like Benjamin Franklin, Rudolf Diesel, and yourself, the Interdependence Council now presents to The Franklin Institute this historic document as a symbol of needs and ideals common to men everywhere."

MR. ROLPH: "Dr. Diesel, Mr. Mallery, Ladies and Gentlemen: I accept humbly for The Franklin Institute this historic document. The records of The Franklin Institute tell us, perhaps some of you here in the room will remember the occasion, Rudolf Diesel was awarded the Elliot Cresson Medal of The Franklin Institute in 1901. So it is that to the Institute comes this one of his early papers in his own handwriting to be cherished and cared for by us. I personally feel and I am sure that most of you agree with me that the Institute should have within its walls such papers by such famous men. These papers point the way to those who follow the directions which have been for the greater glory of all men. The Franklin Institute in its 130 years has sought to bring knowledge of mechanics and the sciences to all who listen and read. With knowledge comes understanding. Understanding not only of mechanics and sciences but also of the men in those fields. Where there is understanding of men and among men there is no mystery—for mystery breeds fear, fear distrust, and distrust engenders hate. So that man will understand man through understanding science, The Franklin Institute was founded and still labors. So that there be understanding of men among all nations, the Interdependence Council was founded. Ladies and gentlemen, we are in agreement. Dr. Diesel, Mr. Mallery, thank you very much. It is now our privilege to hear from an old friend, Mr. Yarnall, Past President of the American Society of Mechanical Engineers and a past member of the Institute's Board of Managers."

MR. D. ROBERT YARNALL: "In the public press it has been announced that in the past year not a steam locomotive was made for use in U. S. A. This amazing Technological change from the steam locomotive to the diesel-electric locomotive has taken place before our eyes—largely in the last 15 years. Let's examine for a few moments this machine which has brought about such momentous changes.

"In the latter half of the last century when the gasoline engine or Otto-cycle engine was in its heyday, it became known that higher compressions produced better efficiency, but that the fuel used at a compression ratio of more than 6 to 1 caused pre-ignition or detonation before any useful work could be done in the cylinder.

"During the 1890's Dr. Diesel, exploring theories set forth by the leading scientists of the day, produced an engine to operate at higher compressions without an ignition system, using an inexpensive fuel that would not detonate in the cylinder.

"This engine, as are present-day diesels, was similar in most respects to the Otto-cycle engine. The chief difference was the application of very high pressure and the use of the heat of high compression to ignite the fuel, thus enabling the use of less explosive fuels.

"In 1924 the Ingersoll-Rand, General Electric Company and American Locomotive Company, exploring the possibilities of the diesel, jointly built a diesel-electric switch locomotive for trial on the Central Railroad of New Jersey. This locomotive proved very successful, especially when working away from maintenance and service points for long periods, and it was put into regular service in 1925. The locomotive is still in every-day operation on this railroad.

"This first successful diesel-electric locomotive was 300 H. P. The cab was built to resemble a freight car with a box-type cab and operating controls at each end. Several other switchers followed, using the same general plan of construction, until in 1927 the American Locomotive Company and General Electric built a 600 H. P. switcher similar in outline to the type now in general service, with a cab at one end. These first 600 H. P. switchers began service on the New Haven Railroad and were the forerunners of the present extensive diesel operation on that railroad.

"The first diesel-electric locomotive for road freight service was put into operation in 1940 by the Electro-Motive Division of General Motors. This was a 5400 H. P. four-unit locomotive, and it was shortly followed by a 4000 H. P. two-unit combination freight and passenger diesel-electric built by Alco-G. E. for use on the New Haven Railroad.

"The diesel-electric has now entirely taken over the switching operations on the railroads; since 1938 class-one railroads have been buying only diesel-electrics for switching service with a few exceptions. Their ability to produce maximum power instantly at zero miles per hour, their use of practically no fuel during standby periods and their ability to work for several days in distant yards with little or no servicing, plus the fact that the fuel supply on the locomotives is sufficient for three or four days' operation, have established them beyond question as the ideal locomotive power for yard and switching work.

"It was natural that this amazing success in yard service should lead to use in road service. In 1937 the Birmingham-Southern Railroad completely dieselized their railroad with 900 H. P. switcher locomotives equipped for multiple-unit operation, which enabled the use of 1800 H. P. for heavy drag work on the main line. This was the first railroad in the United States to make a complete change from steam to diesel operation and the change has been very successful.

"During this development period many changes were being constantly made in the layout, control and electric equipment. Streamlining was developed for road use and chassis were enlarged to take two engines on one frame to develop the high horsepower demands of road service. Gearing was improved to get the high speeds necessary for passenger service, until now it is possible to get nearly any combination of horsepowers and speed, up to 6000 H. P. and 129 miles per hour.

"The locomotive type diesel engine today is directly connected to the traction electric generator, which provides power for the traction motors. Multiple-unit control gives extreme flexibility and enables the locomotives to be used in the proper combination for the type of service they are to perform.

"When these locomotives are properly used they will give efficient, trouble-free and cheap transportation for many years without costly overhauls.

"The nature of the design is such that when a major part is in need of repair or overhaul it can be removed from the locomotive and another similar part put in its place, thereby keeping the locomotive in the shop for a minimum time, while the part in need of repair can be worked over without delaying the locomotive.

"A few years ago The Franklin Institute awarded to Hermann Lemp the Henderson Medal for his development of electric transmission for Diesel locomotives. This successful system greatly accelerated the acceptance of the Diesel locomotive by American railroads.

"The diesel-electric locomotive now has a definite and established place in the railroad industry, and it will not soon be displaced. Many railroads are 100 per cent equipped with diesels and many more will soon follow. The past years of operation have evolved operating and maintenance techniques to obtain the ultimate of service. The builders are constantly developing and improving their locomotives. A standard of operation and maintenance has been developed far beyond that ever undertaken during steam operation, until now the problems are the same on all railroads.

"Some months ago I boarded in Chicago the Santa Fe's famous "Chief"—a diesel-electric propelled train—and at a high rate of speed traveled in reasonable comfort night and day to Los Angeles. There were six different operating crews used, a few station stops, when fuel tanks were quickly refilled while passengers loaded and unloaded. We landed in California exactly on time, and to my amazement the same beautiful train, after a cleaning crew had freshened things up, and the position of the locomotive had been changed end for end, started right back for Chicago. Yes, this availability of the diesel-electric locomotive is largely responsible for its having replaced the steam locomotive.

"An idea of the German engineer has revolutionized American Transportation.

"To be sure, toward the end of the Nineteenth Century there were others working actively in the internal combustion engine field; but the history of the period tells us that Dr. Rudolf Diesel "proposed to compress air only in the cylinders of such an engine and to inject the fuel—in this case, at first, crude oil—when the end of the compression stroke was reached."

"The history of this period also discloses for us a most interesting fact, which is that in 1901 Dr. Rudolf Diesel was awarded the Cresson Medal by The Franklin Institute for this outstanding invention.

"So to Dr. Rudolf Diesel we acknowledge our great indebtedness; and we rejoice that The Franklin Institute is to be the place of safe-keeping of the original manuscript of Dr. Diesel's ideas for the application of the diesel engine to the locomotive.

"In giving honor to Dr. Diesel for his great invention we also would pay tribute to the host of other creative engineers who have helped to make the application of the Diesel engine so useful to civilization.

"In such creative enterprises as this we are dependent one upon another—we are indeed interdependent the world over.

"Engineers are always expected by their countrymen to carry their full share of the load in national crises. Great as is the urge to cooperation in war times, when we are aware of common danger, the challenge of living and growing together in peace is still greater in these postwar days of 1954. The need for human well-being, for the common good in which all share, is a challenge to our citizenship. Our acceptance of this challenge is an act of faith.

"The work of the engineer at his best is based on faith: Faith in the natural laws governing the universe; faith in the ability of men to design, construct and operate machines based on these laws; faith that men can modify their physical environment; faith that backbreaking toil can be transferred to machines; faith in the interdependence of man and man.

"The nature of the engineer's training establishes his faith in truth and integrity. His confidence in the future is strong. He believes that men are capable of living together in peace. In spite of crises that may come the faith of the engineer is unshaken.

"Dr. Rudolf Diesel was an engineer whose faith in a new idea has helped to transform the U. S. A. railroad system to the great benefit of all Americans.

"We thank you, Dr. Eugen Diesel, Honorary Secretary of the Council of the Deutsche Museums, and Otto Mallery, President of the Interdependence Council, for your faith in The Franklin Institute; you can rest assured this precious manuscript will have an honored place among the valued archives of this venerable institution which bears the name of another great inventor, Benjamin Franklin."

Perry

[illegible]? RAE

BOOK REVIEWS

Chemical Business Handbook, edited by John H. Perry. 1369 pages, diagrams, 20 × 26 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $17.00.

Anyone familiar with Perry's *Chemical Engineers Handbook* now in its third edition, will not be surprised at the tremendous amount of really worth-while information which the late Dr. Perry skillfully assembled into a single volume. While this book is issued as one of McGraw-Hill's Chemical Engineering Series, it will be useful to all scientists and technologists in any industry where chemistry plays a part. As editor of a group of 124 contributing specialists, Dr. Perry took as his objective the presentation of the "facts of life" in the business area for the technical man, particularly those in executive positions. On the sound basis that "it is becoming more and more essential that the industrial employee be skilled in, or at least familiar with, many phases of business beyond his own specialty," this book is designed primarily as a convenient general reference. It should provide the required answers to most of the specific business problems that face the technical man as he broadens his operations in any phase of his industry.

With over thirteen hundred double column pages, filled with concise discussions, tables, graphs and diagrams, this is not a book to be read from cover to cover. However, the text is written in such a way that specific subjects can be studied conveniently when the need arises. While it is not a substitute for courses or detailed textbooks, it can serve to orient the reader in a new field. The presentations are designed for those with little or no direct training or experience in the subject. In addition there are numerous pertinent references in each section of the book. For the more experienced, there is always something to be learned from the writing of real experts.

The handbook will probably be opened most frequently for solving specific problems. It will be a rare case where no help at all can be obtained. The excellent indexing system should permit rapid location of the required information. The charts, check lists and data tables will be referred to often by regular practitioners as well as novices.

To try to give a general summary of the coverage of the *Chemical Business Handbook* would take too many words for a review of this kind. The technical man will find understandable and useable presentations of finance, accounting and cost control. Technical and market research and development are treated both philosophically and practically with many pages of data and examples. The functions and procedures of production, engineering, purchasing and traffic are unusually well presented for industries based on technology. The discussions of sales, advertising and public relations provide appreciation of the value of these promotional subjects to an enterprise. Personnel, patents, business law, insurance and many other pertinent topics are thoroughly discussed. Finally, sections on report preparation and mathematical techniques provide valuable guidance and suggestions in the handling and transmitting of business information.

It is quite obvious that your reviewer is enthusiastic about the *Chemical Business Handbook*. He is moving a few books over on his shelf so that this new Perry-edited book can go beside his *Chemical Engineers Handbook*. He expects to use the new one as often in the years ahead as he has used the old one in the past.

Austin W. Fisher, Jr.

Nickel in Iron and Steel, by A. M. Hall. 595 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $10.00.

Almost every element has been added to iron in attempts to improve its properties. These attempts have resulted in the development of many new alloys that have played an important role in the tremendous expansion of the steel industry. One of the most important alloy additions to iron-base alloys is nickel. The vast amount of data available on nickel as an alloying element has been assembled, edited, and presented in this book to serve as a detailed source for the metallurgist and engineer.

In contrast to most steel alloying elements, nickel has been used for many years. For example, it was first used in the Damascus steels over 200 years ago, and has been used continuously in the armor plate industry since 1885. Such extensive and long continued use of nickel in steel has resulted in a vast store of knowledge and must have presented a formidable task to the author to edit and present the material coherently.

The fifteen chapters in the book cover the melting and working of nickel alloy steels, mechanical and physical properties, metallography, heat treatment, corrosion, and fabricating. Approximately half of the material is devoted to nickel in cast steels and irons.

The nature of the book makes it difficult to read; however, it is doubtful if the average reader would find it necessary to cover the entire text. Its value lies primarily in its use as a reference text and as such should save the reader many valuable library hours. Very detailed and up-to-date information is given, especially on the physical and mechanical properties of the various alloys.

The author has improved the readability of this volume considerably by summarizing each chapter. These summaries are generally one to three pages in length and help the reader to digest and interpret the mass of factual data presented.

An extensive bibliography of 784 references is appended, some of these being as recent as 1953. Both a name and subject index are included. This book maintains the high standards set by the preceding volume, "Aluminum in Iron and Steel" and should prove to be an invaluable aid to those interested in nickel-alloy steels.

R. L. SMITH

SUPERFLUIDS, by Fritz London. Volume II, Macroscopic Theory of Superfluid Helium. 217 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $8.00.

The Macroscopic Theory of Superfluid Helium is the long awaited companionpiece to Volume I, "The Macroscopic Theory of Superconductivity," which was published in 1950. It somehow seems fitting that these volumes summarize the progress in those fields to which Dr. London had devoted so much of his efforts for a good many years and represent his last publication before his untimely death.

The present volume is devoted to a fairly detailed summary of the development of present-day knowledge concerning the behavior of liquid helium below its λ-point. The first chapter describes the discovery of the two phases in the liquid and the subsequent observations of the remarkable properties of the second phase, helium II. Subsequent development which includes a detailed study of an ideal Bose-Einstein gas and its characteristic condensation phenomenon, is directed toward a logical evolution of the two fluid model of helium II.

This model, introduced by Tisza, divides the liquid into two components, the normal fluid and the superfluid. The superfluid, corresponding to the condensed phase of a Bose-Einstein liquid, is considered to have zero entropy and zero viscosity. It is, of course, the attributes of the superfluid which give rise to the remarkable behavior of helium II.

A detailed discussion is also given on the quantization of hydrodynamics and the theory due to Landau which paralleled that of Tisza. The relation between the phonon excitations and "second sound" is thoroughly explored. "Second sound," unique in helium II, is a thermal wave analogous to the pressure wave of ordinary "first sound," and is predicted by both theories. Dr. London points out that the fundamental difference between the two theories is that the assumptions of Tisza's theory restrict the particles which make up the liquid to those obeying the Bose-Einstein statistics; whereas Landau's theory makes no such restriction and is applicable to a liquid without regard to the statistics obeyed by its fundamental particles.

Naturally, available helium is composed of the isotope He^4 which obeys the Bose-Einstein statistics. However, in recent years, with the development of the nuclear reactor, isotope He^3 has become increasingly available for experimentation. To date no phase transition has been observed in the He^3

liquid. This isotope, containing an odd number of nucleons, obeys Fermi-Dirac statistics rather than Bose-Einstein statistics and an ideal Fermi-Dirac gas has no condensation mechanism. Realizing the importance of understanding the properties of liquid He^3 on the evolution of a microscopic theory of liquid helium. Dr. London devotes a chapter to the discussion of pure He^3 and mixtures of He^3 and He^4.

As a whole, this volume is clear, well written and easy to read for the reader having adequate background. It is a desirable addition to the library of anyone interested in the theoretical foundations of our present knowledge of the behavior of liquid helium.

JONATHAN GITTLEMAN

have

MODERN PHYSICS FOR THE ENGINEER, edited by Louis N. Ridenour. 499 pages, diagrams, illustrations, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $7.50.

During the academic year 1947–48 a series of lectures was presented at the University of California at Los Angeles for the purpose of familiarizing engineers with current advances in physics. The lectures were delivered by visiting professors excelling in a particular branch of science. The course was so well received that it was repeated in the academic year 1952–53. *Modern Physics for the Engineer* is the outgrowth of these lectures. Edited by L. N. Ridenour, Vice President of the International Telemeter Corporation and Visiting Professor of Engineering at U.C.L.A., the book contains articles by such well known men in physics as W. Bleakney of Princeton University, Frederick Leitz of the University of Illinois, W. D. Hershberger of U.C.L.A. and L. B. Loeb of the University of California.

The book has been divided into three parts: the Laws of Nature, Man's Physical Environment, and Information and Its Communication. Under the laws of nature, such fundamental subjects as relativity and the foundations of mechanics, atomic structure, physics of the solid state and magnetism are discussed. Also, nuclear structure and transmutation, electronuclear machines and the actinide elements and nuclear power. Under Man's Physical Environment, such subjects as astrophysics, high-pressure phenomena with applications to geophysics, the earth beneath the sea, thunderstorms and lightning, and transient phenomena in supersonic flow are described. Under Part III, there is much on the latest developments in communications. Here the subject is introduced with a description of electrons and waves, and of semiconductor electronics. With this background, communication theory and the transmission of information, and computing machines and the processing of information are fairly well discussed. The book is concluded on an encouraging note. We are now in the beginning of the second industrial revolution and many believe that vast technological unemployment is inevitable. However, Mr. Ridenour suggests that if we compare this revolution with the first, the result of the second may be to "let men move on from degrading routine tasks to perform at a higher and more challenging level . . . the machines may be pushing us not toward disaster, but rather toward ever greater individual achievement and satisfaction."

For the engineer and student who wants to keep abreast of the current developments in physics, reading *Modern Physics for the Engineer* is an easy way to enlightenment. The changes in physics in the last ten to fifteen years are remarkable. And on the basis that the physics of today is the engineering of tomorrow, it behooves the aspiring engineer to get up-to-date.

E. W. HAMMER

have

ACOUSTICS, by Leo L. Beranek. 481 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $9.00.

This book should be welcomed by all teachers, students, and other workers in the field of acoustics. It includes thorough theoretical analysis of most of the topics with which the serious worker should be familiar.

In the preface the author warns the reader that there "is no easy road to understanding present-day acoustics." Acoustics is still largely an art, and this author has brought it closer to a science by writing his book. He parallels the electrical circuit theory in his method of handling equations. However, one of the important aspects of circuit theory is a standardized notation. The lack of this has always been one of the great difficulties hampering the acoustics student. Different authors use different notations, and some authors change their notations.

The present author has recognized this difficulty and has explained his notation in Chapter 1. This reviewer would like to see the electric circuit theory followed more closely in the use of lower case letters for time varying quantities and upper case for mean and r.m.s. values. The author prefers to use $u(t)$ for the time varying quantity and u for the r.m.s. However, in Chapter 2 he uses the same letter u for both r.m.s. and time varying values (Eq. 2.30 and 2.43). This will cause difficulty for the student.

The material on radiation of sound and acoustic elements is particularly fine. The discussion of radiation impedances is also very satisfactory. The Chapter on microphones is unfortunately terminated too soon. The use of gradient type microphone of high orders is so extensive that to maintain balance a corresponding discussion should have been included.

The treatment of loud speakers and enclosures, of noise control and transmission, and of sound in enclosures is all excellent. It would be of further assistance to the sound engineer and high fidelity fan to have included more on the transient response of loud speakers. In the general treatment of noise better unity might have resulted if the work on "transmission paths" were combined with the treatment of "sound transmission through walls."

A difficulty in the way of a serious student in the present art of acoustics lies in the following. It is assumed that the thermodynamic transformation during the existence of a sound is an adiabatic or isentropic one. The equation of state of an isentropic is simple and can be integrated exactly to determine changes in the potential energy. The result of this exact integration, however, is not satisfactory and is discarded. Instead, an approximation is made to obtain a preferred result different from the exact one. The reviewer on first looking at the present book expressed a hope that this difficulty would be resolved and that a satisfactory explanation of this anomaly had been included. It was a great disappointment to find the same undefended approximation in use. For those unfamiliar with this defect in the art or science note that the solutions to the basic equations are written to the first order to obtain particle velocity, excess pressure, and other parameters. Energy density on the other hand is a second order parameter and first order formulas, therefore, should not be depended upon for its computation.

The chapter on measurements is unexpected in a book on theory. Since measuring instruments and methods may change so radically in time, such topics are usually separated from the corresponding basic theory. If the author prefers making this available to the student in the theory text, perhaps an easily revisable appendix would be more suitable.

One other item for elimination is the table of decibels and voltage and power ratios. The decibel as a power ratio is a simple concept, the formula for computation is simple and such a table is not necessary. The decibel as a voltage ratio in general is meaningless unless certain conditions are satisfied. Since these conditions are not stated in the table the more casual student may be in difficulty.

The chapter on hearing, intelligibility, and psychoacoustics is an excellent contribution. This treatment unfolds for the early student the possibility of studying in a comparatively new field, one in which great activity is now taking place. Of all the avenues for further study which include super-sonic speeds, ultrasonic vibrations, architectural acoustics, sound ranging in water, seismic exploration, musical instruments, and others the author is to be congratulated upon his choice.

HARRY SOHON

MONOMERIC ACRYLIC ESTERS, by Edward H. Riddle. 221 pages, 16 × 24 cm. New York, Reinhold Publishing Corp., 1954. Price, $5.00.

Presented in this rather brief volume is the latest information on the chemistry and chemical engineering of the commercially available monomeric acrylic and methacrylic esters. Because of the enormous amount of data available on the chemical reactivity and copolymerizability of the acrylic esters, individual reactions are necessarily given cursory treatment. However, there are extensive and up-to-date literature references for the reader interested in specific details on a particular subject. One of the most valuable features of the book for the research chemist is the chapter devoted to the important methods of polymerization, and to the most recent theories regarding the polymerization mechanisms. An indication of the completeness of this section of the book is given by the following polymerization methods discussed therein: suspension, bulk, emulsion, graft, and block polymerization by normal catalysis and also by redox and ultra-violet catalysis. For the chemical engineer, problems such as the prevention of popcorn polymer formation, explosive limits, and pumping requirements are discussed in detail.

The book itself is made up of seven chapters covering three broad subjects: (*a*) Safe Storage and Handling Problems, (*b*) Reactivity, Polymerizability, and Copolymerizability of Acrylic Esters, and (*c*) Analytical Methods for Checking the Purity of Acrylic Monomers. Many tables and graphs are also included describing the physical and chemical properties of both the monomeric and polymeric forms of the esters.

Research chemists, industrial chemists, and chemical engineers involved in either the production or use of acrylic esters cannot afford to be without this book. Because of the completeness and conciseness of this volume it should also be considered as an excellent addition to the reference shelf of chemical libraries. DONALD H. RUSSELL

ENGINEERING ANALYSIS, by D. W. Ver Planck & B. R. Teare, Jr. 344 pages, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $6.00.

Doctors Ver Planck and Teare have hit upon the idea of teaching general engineering procedures of analysis by means of a book of case histories. One cannot say this book belongs to any particular branch of engineering more than another, for here will be found problems of electrical, mechanical, hydraulic, and heat engineering, and even more unclassified branches of science.

Essentially, these problems are presented by the authors' statement of what is known and what is desired. Thereafter, certain basic questions about the particular situation are asked and answered. In this way the authors are gently saying, "Here is how to go about thinking out a problem of this type," and it becomes evident that there are some common thoughtways to be traveled regardless of the details.

Now, some may ask about the value of a course of this type, wondering whether "thinking procedure," which is basically what this is, can be successfully taught. In response to this question it must be observed that many newly graduated engineers entering their professional careers have formed the habit from their school work of expecting to find the problem to which they are assigned worked out somewhere. It is true that there is a great deal of routine mathematical analysis which is a repetition of what has already been done, but a good engineer should not be wasted in such activities. Therefore, it can certainly be said that the teaching of engineering analysis should counteract this early impression that true engineering is a matter of routine detail. Training of this type should stimulate the engineer to seek a fresh approach to the solution of the problems handed down by his superiors and to separate the original from routine work.

These authors have sensed the need for a course which will supplement the usual objectives, absolutely essential, which are the imparting of new subject matter, new technical principles, new techniques. Hence, they have attempted to expose the student to professional method in which he must analyze and formulate the problem out of the very often vague statements of a busy superior or a confused client. In the hands of an experienced and enthusiastic teacher such a course should help to produce high calibre engineers. C. W. HARGENS

ELECTROMETRIC pH DETERMINATIONS, by Roger G. Bates. 331 pages, 15 × 23 cm. New York, John Wiley & Sons, Inc., 1954. Price, $7.50.

In today's scientific world, the measurement of pH is widely used in the research laboratory, the control laboratory, the clinic and the factory. By the discovery of the hydrogen ion function of glass membranes and the development of convenient practical glass electrodes, electrometers that allow the potentials of these electrodes to be measured rapidly and accurately, and controllers that permit the pH of process solutions to be regulated automatically, far reaching application has been made of pH measurements. As is so often the case, the "technology of pH instrumentation has far outdistanced the slow progress toward an adequate understanding of the meaning of the numbers that pH meters furnish so easily." It is upon this last statement that the author bases his purpose of the book.

Because of the complex notations in the theory of pH, the author first eliminates misunderstanding and confusion by discussing fundamental principles and conventions.

The need for order in the field of the pH scale is very evident. The author has discussed the evolution of the pH notation and compared the various possible pH notations as to their validity and usefulness in an effort to unify the subject.

The chapters on pH standards, pH scales and the properties of glass electrodes contain a review of each subject.

The text consists of ten chapters, six appendices, and a subject and author index. The book is very well composed and well illustrated by diagrams, graphs, informative tables and derivations of formulae. There is so much varied information on the entire subject of pH, that it is rather difficult to review all the contents. Even if this were not the case, the availability of information about pH in one text would be enough to commend it as an addition to the scientific library. All in all, the theory and practice as set forth in the text are concise and to the point and more than fulfill the need for such a text. PHYLLIS A. PARKIN

NUCLEAR SPECIES, by H. E. Huntley. 193 pages, diagrams, 15 × 22 cm. New York, St. Martin's Press, Inc., 1954. Price, $4.50.

Many books on nuclear physics have appeared since the advent of the atomic age. They have ranged from the mass-educating superficial books to the abstruse used in graduate study. It is inherently difficult to present a comprehensive book on this topic and not omit significant details. However, Professor H. E. Huntley, Professor of Physics at the University College of the Gold Coast, has succeeded in writing a thoroughly lucid, competent and authoritative treatise on nuclides. The treatment as far as possible is non-mathematical.

In Chapters I and II, comprising about 40 pages, there is delineated a highly intelligible account of the atomic nucleus and its size. These two chapters constitute one of the clearest expositions this reviewer has seen.

Chapter III deals with isotopes, their discovery, nature, mechanics of separation and determination of mass.

In the chapter on Natural Nuclides, five empirical rules are enunciated for accounting for the proton-neutron content. A significant section deals with the stability of the heavy elements and this dependence on the excess of neutrons.

Of fundamental importance are Chapters VI and VII dealing with mass defects and binding energies.

Some minor points can be cleared up in a future edition. Table 1.1 contains slightly more than half of the particles now recognized by the physicist. Also, recently we have been told that the negative proton has been detected!

On page 64 the author says: "Had the terrestrial nuclides been charted a few million years ago, the representation must have included members of the neptunian radioactive family, long since decayed." The author probably means "a few billion years ago."

On page 181, astronomical evidence has doubled the distances of the distant galaxies and has so doubled the time scales which would make the beginning epoch of the "big boom" some 3.6×10^9 years ago.

I. M. LEVITT

THE PROPERTIES OF GLASS, by George W. Morey. Second edition, ACS Monograph No. 124. 591 pages, diagrams, 16 × 24 cm. New York, Reinhold Publishing Corp., 1954. Price, $16.50.

For the glass technologist, and for the technical man who has occasion to require information regarding specific properties of glass, this book is of real value. Its scope ranges from an interesting description of the history of glass through adequate and lucid definitions of the physical and chemical, mechanical and other important properties of the subject material. For the rheologist, the chapters on viscosity, surface tension, and elasticity of glass may represent a challenge.

The author wisely presents a number of definitions of glass in addition to his own, and one is left with the feeling that no one description is necessarily exclusive. There follows a clear exposition of the phase rule and how it is applied to a number of binary, ternary and multicomponent systems. Included in this discussion are numerous phase equilibrium diagrams with the details which usually accompany these diagrams. The factors that affect devitrification are described in some detail. The chemical kinetics of the process and the role of surface energies in this vital mechanism of glass manufacture are discussed.

There follows a series of chapters devoted to specific aspects of glass technology, each chapter a relatively independent study. This type of presentation enhances its value as a reference. Such important phases of glass manufacture and fabrication as annealing, chemical durability, thermal conductivity and expansion are defined, and discussed with ample references and data. Virtually every property of glass is described that has industrial significance. They include hardness, electrical and magnetic properties, optical characteristics, strength, and composition. These studies represent only a partial list of the subjects contained in the book, and are presented in an easily readable style. There is a minimum of speculative material, and a maximum of what appears to be data and information based on scientific investigation.

S. N. MUCHNICK

QUALITATIVE ANALYSIS USING SEMIMICRO METHODS, by Esmarch S. Gilreath. 287 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1954. Price, $4.25.

In past years, the usual textbook for any college course concerning itself with qualitative analysis was little more than expanded flow sheets of the qualitative separation of anions and cations according to their comparative chemistry, plus a few problems. This existing condition did little or nothing toward the encouragement of the student to acquaint himself with the theory behind many analytical procedures.

The author of the text is well aware of the need to supply the student with a simplified explanation of the basic concepts of physical chemistry. This knowledge is prerequisite for such concepts as solution, precipitation and complex ion formation, upon which the science of qualitative analysis depends.

The text is composed of twenty-two chapters and fifteen appendices. It is not exceptionally well illustrated by schematic diagrams, graphs or informative tables; and the flow sheets for analysis are rather obscure.

Part I is comprised of ten chapters on the theoretical aspects which are namely: forces between atoms, solutions, chemical equilibrium, ionization of weak electrolytes, solubility product principle, hydrolysis, complex ions, colloids, and oxidation-reduction theory. As has previously been inferred, the discussion is very simple and all calculations are possible with a knowledge of arithmetic or very simple algebra. The discussion is concluded by problems, questions or exercises on the theory.

Part II is comprised of twelve chapters on experimental procedures consisting of general laboratory directions, Groups I–V cations and Groups I–V anions, and a complete analysis. The chapters on each group consist of a theoretical discussion, analysis discussion, flow sheet form of analysis, notes on analysis, and pertinent chemical reactions involved in the separation and identification of the group.

The appendices provide the information necessary to the successful completion of the experiments.

The author must indeed be commended in his attempt to correlate a theoretical discussion with the laboratory procedures, and therefore for removing from the qualitative analytical chemistry course some of the reputation for "cookbook" chemistry acquired only by pure memorization.

PHYLLIS A. PARKIN

WATER SUPPLY AND WASTE-WATER DISPOSAL, by Gordon Maskew Fair and John Charles Geyer. 973 pages, plate, diagrams, 16 × 24 cm. New York, John Wiley & Sons, Inc., 1954. Price, $15.00.

Supplying a community with water and subsequently disposing of it demands a wide knowledge of sanitary engineering. It requires an understanding of rainfall and ground water as sources of supply, of the storage, transmission and distribution of water; of the chemistry and biology of water; and of the collection and disposal of sewage. *Water Supply and Waste-Water Disposal* treats all of the important aspects in this branch of civil engineering. Written by G. M. Fair, Professor of Sanitary Engineering and Professor of Engineering at Harvard University, and by J. C. Geyer, Professor of Sanitary Engineering at the Johns Hopkins University, the book reflects the many years of practice and teaching each has devoted to his profession.

Although not designated as such, the first half of the book deals primarily with the supply and disposal of water, while the second half is concerned with the treatment of water and waste water. Containing almost a thousand pages, the book is too long to go into a detailed review. In the first part however, following a sort of introduction to the subject on the elements of water sanitation, there ensue descriptions of water-supply and waste-water-disposal systems. Since the civil engineer must study many numerical observations and measurements in order to design water works, pertinent methods of statistical analysis are explained and illustrated. As sources of supply, rainfall and runoff, the storage and regulation of runoff, ground water and its collection, and surface water and its collection are discussed. The transmission of water through conduits and pipes and its distribution are described; and finally, sewage, its flow and collection.

The second half of the book begins with the physical properties and chemistry of water. Helpful and harmful living organisms, both animal and plant, that inhabit waters are described under the biology of water and waste water. The explanation of the various methods of purifying water, such as sedimentation and flotation, chemical coagulation and precipitation, filtration and biological flocculation and precipitation follows. The principal by-product of the treatment of water and waste waters is known as sludge. The methods of sludge treatment and its disposal, often useful, are explained. The book closes with chapters on industrial and rural water supplies and means of waste-water disposal.

The subject matter in each chapter is approached in the same thorough manner: each begins with the general considerations, advancing then to the particular pertinent sub items. Where possible, practical examples are presented to illustrate the text. Needless to say, there is an extensive bibliography at the end of the book pertaining to the individual chapters.

There isn't much doubt that *Water Supply and Waste-Water Disposal* is a significant contribution to the literature on sanitary engineering. For student and practicing engineer alike, this should be a worthwhile addition to his library.

E. W. HAMMER

FUNDAMENTALS OF ELECTROMAGNETIC WAVES, by Paul C. Shedd. 191 pages, diagrams, 15 × 22 cm. New York, Prentice-Hall, Inc., 1954. Price, $4.25.

Professor Shedd's book is intended for seniors in electrical engineering or in physics. Its scope carries the student into Maxwell's equations, with applications to rectangular wave guides and to simple antennas. The title is somewhat misleading, since less than one fifth of the text is devoted to electromagnetic waves, the major portion of the book discussing general electromagnetic theory. Interspersed throughout the text are chapters on vector analysis as required.

When a new text is offered in a field already well covered, the reader is justified in expecting some novelty in point of view, pedagogic design, or in illustrative applications. The present book undoubtedly reflects the author's teaching experience, and must be well adapted to the courses he gives. The novelty is principally in point of view, and does not appeal to this reviewer.

The introduction establishes the point of view as that of a postulational, deductive formulation of the theory, and seems to promise a "theorem-proof" treatment in the manner of Euclid. Whether so formal a treatment is desirable at the senior level is questionable; at any rate, we do not feel that this text really achieves the logical compulsion that such a formulation should have.

The basic ground rules are all stated in Chapter 4. They consist of the basic phenomena, the restriction of the domain of interest, and four postulates. The basic phenomena are mechanical forces between mass particles, and electrical forces between electrical particles. The domain is restricted to the macroscopic, and quantum mechanics is specifically excluded since it pertains only to the microscopic domain. Postulate One embodies the principles of conservation of energy and conservation of charge. Postulate Two, the principle of continuity, establishes electricity as having a dual nature—the charged particle and the flux emanating from that particle. Interaction of this all-pervading flux and other particles is offered as an "explanation" of electrical forces to replace "action at a distance," which is rejected as futile, and "strain in the ether" which is considered as cumbersome and uneconomical, perhaps ridiculous. Postulate Three is the principle of superposition. Here "homogeneous," "isotropic," and "linear" are defined as descriptive of characteristics of a region, but are immediately applied to the emanation from a particle, rather than to the region. Postulate Four is the special principle of relativity.

Relativity is introduced to discuss fields arising from charges in motion, leading to the electrodynamic field in addition to the electrostatic field. However, this is never used in its exact form. Rather in the approximate, "usual" cases of speed small compared to that of light, the relativity correction factor is suppressed, by the electrodynamic field remains, demonstrating that the postulate of relativity was not required for its derivation.

There are a few other novelties, such as treating surface charge as a vector quantity, having the direction of the surface normal, and such as using "in phase" as applied to vectors to mean "collinear," or "parallel."

In general, the organization of the material and its exposition leaves much to be desired. It is choppy; the thirty-two chapters have an average length of five pages. The impression is of a set of lecture notes transcribed with no explanation or exposition. About eighty problems, arranged by chapters, are placed at the end. For some chapters there are no problems. A. C. BYERS

THEORIE ET TECHNIQUE DE LA TRANSMISSION TELEGRAPHIQUE, TOME 1: THEORIE, by R. Roquet. 252 pages, diagrams, 21 × 29 cm. Paris, Editions Eyrolles, 1954. Price, 2,750 fr.

This is the first volume of a proposed series devoted to telegraph transmission. This volume, concerned with the theory, is written with a meticulousness that is quite rare in books of this type. The subject is developed in an extremely logical and elegant manner.

After a brief introduction defining the subject and its vocabulary, the remainder of the book is divided into three major sections. Part One deals with the nature of telegraph signals, with signals as carriers of information, and with the nature of distortions of telegraph signals.

The second part is the largest section of the book. As we have said, Part One is concerned with telegraph signals, and now Part Two is concerned with their transmission. This part describes various types of modulation; transmission lines and transient phenomena in transmission lines; and demodulation at the receiver. Problems concerned with distortion, their causes, and methods of reducing distortion are discussed. Consideration is also given to the bandwidths required for transmission of telegraph signals.

The final part of the book is devoted to a discussion of the application of the theory to practical problems.

This volume is primarily of interest to a particular group of specialists. However, telegraph transmission is essentially communication with pulses. Hence some of those who use pulse techniques in communication or in computers might be interested in looking into this book. H. L. PLATZER

EXPLORING MARS, by Robert S. Richardson. 261 pages, plates, diagrams, 14 × 21 cm. New York, McGraw-Hill Book Co., Inc., 1955. Price, $4.00.

Here is a prediction: Astronomy books to be popular will have to be linked to a space travel theme. This has been in evidence for the past two years. Now another popular astronomy puts in an appearance masked by this space travel theme. However, this book is different. This book comes from the facile pen of a ranking astronomer who has also made his mark as a serious space travel enthusiast.

Exploring Mars is an intriguing book concerning the red planet. Dr. Richardson discusses oppositions and programs for observing in both 1954 and 1956. In an ingenious manner the Keplerian laws are introduced, explained and the lesson is significantly painless.

In Chapter III the author gets the reader into space and the mechanics of space travel. Chapter IV comprises a work for which Dr. Richardson is justly famous—the establishment of the astronomical observatory on the moon. Travel times and paths to the planets are then described and in Chapter VI a Martian calendar—something with which this reviewer is intimately associated, being the originator of one mentioned in the book —is described. This reviewer admits he was surprised to find this calendar mentioned as it was released only a short time ago.

From that time we get into the atmosphere of Mars—the challenging and provocative possibility of life, both vegetable and animal—and finally the fantastically stimulating question of the canals is thoroughly explored.

From here the author does the thing which comes naturally, at least to an astronomer, and leads the reader into a highly articulate description of the solar system.

There are some items which are questionable and which the author may alter in a future edition. It has recently been shown that there were no riots in England because of the adoption of the Gregorian calendar. As stars of magnitude 6.5 are shown in the planetarium and these can be woven into the constellation figures with no difficulty it should not "be hard" to trace the outlines of the familiar constellations.

The book is well written, realistic, authoritative and will be well received. It is unfortunate that the publication could not have been delayed for a year to take full advantage of the tremendous impact of the next close approach of Mars in 1956.

Exploring Mars would have been a guaranteed "best seller" with better timing.

I. M. LEVITT

ANALYSIS OF DEFORMATION. VOLUME I, MATHEMATICAL THEORY, by Keith Swainger. 285 pages, diagrams, 15 × 22 cm. London, Chapman & Hall, Ltd., 1954. Price, 63s.

This book evolves a generalized approach to the deformation of both elastic and plastic bodies. It also approaches generalized deformations through linear differential equations, but with non-constant coefficients, and eliminates certain difficulties in the elastic theory of linear infinitesimal deflections. In place of an analytical approach, the author uses vector (and tensor) analysis throughout. While the use of vector and tensor analysis has gradually been extended in the theory of elasticity, we usually find a combined analytical approach. This book completely eliminates the long hand form. On this score, the author's approach is entirely in keeping with vector and operational methods.

This book greatly extends the approach to correlating the stress-deformation theory of bodies by similar notation for vector fields in the generalized field theory in electrostatics and electromagnetism.

Since a stress is the mutual action or interaction between any two parts of a body *per unit area* across an imaginary prescribed section which separates the parts, it lends itself, mathematically, to be uniquely described as a second order tensor. Stress, per se, cannot be vectorially compounded except when acting on the *same* plane of action. Thus for the equilibrium conditions for a tetrahedral element subjected to stress, we compound as vectors the total force as determined by the magnitude of any component stress and its particular area as related to its base area through its direction cosines.

In Chapter II, the author somewhat loosely defines "stress" as the force per unit area. The tensor properties are shown through the vector stress with subscripts for the plane of action. The components of the stress vector per unit area S_i are not necessarily normal to the plane of action $\bar{i}$, but are usually subdivided into components normal and tangential to the plane, or they may assume directions along the principle axis; that is, with components $\bar{S}_{ii}$, $\bar{S}_{ij}$, $\bar{S}_{ik}$, any component area, as related to the base area, is given by $\alpha\bar{c}_i\bar{n}$ where α is the *base* area. Thus $\bar{S}_{ij} \cdot (\alpha\bar{c}_i\bar{n})$ is the vector force acting on the i^{th} area in the direction j. Since $\bar{S}_{ij} = S_{ij}\bar{c}_j$ then, for equilibrium in their respective i, j, k directions, noting the conjugate relation of the shear components $\bar{S}_{ij} = \bar{S}_{ji}$, the author establishes the stress dyadic,

$$S = \sum_{ijk} (S_{ii}\bar{c}_i\bar{c}_i + S_{ij}\bar{c}_j\bar{c}_i + S_{ik}\bar{c}_k\bar{c}_i).$$

The work covers an extensive discussion on deformation analysis, with an interesting discussion of stress-strain relations. The greater complexity of plastic straining compared with elastic strain is pictured through an aggregate of discrete points, in a form of an ideal lattice. Other chapters discuss visco-elastic isotropic substances, a general discussion of yield, thermal strains and the so-called potential energy for thermo-elasto-plastic deformation and elasto-plastic isotropic substances.

The author supplements the work with a welcome appendix on vector analysis. His references show him to be a good student, but he omits the important work by L. Silberstein on "Vectorial Mechanics." The author is to be congratulated on an important contribution with new concepts and ideas.

RUPEN EKSERGIAN

GRIGNARD REACTIONS OF NONMETALLIC SUBSTANCES, by M. S. Kharasch and Otto Reinmuth. 1384 pages, 16 × 24 cm. New York, Prentice-Hall, Inc., 1954. Price, $15.00.

This book is a massive and comprehensive survey of the Grignard reaction by investigators of recognized authority in the field. The authors have restricted their consideration to Grignard reagents that behave "as though the magnesium were directly linked to carbon," and have excluded the reactions of Grignard reagents with other metallic compounds.

The first five chapters (137 pages) are given to a brief historical introduction, a detailed and critical discussion of the preparation (86 pages), the estimation and detection (6 pages), the constitution and dissociation (15 pages), and radical reactions (20 pages) of Grignard reagents. Then follow chapters on the reactions of the Grignard reagent according to the type of co-reactant. The arrangement of the material in these chapters is described by the authors as follows: "Whenever possible a chapter content includes: a brief historical resume, a definition of the so-called "normal" reaction (or reactions) and some consideration of probable mechanisms, descriptions of some exemplary preparative procedures, definitions and theoretical discussions of various so-called "abnormal" reactions, and a tabulation (or tabulations) of literature data. Chapter VI (Aldehydes and Ketones) perhaps best exemplifies the 'full treatment.'" Comprehensive tabular summaries, 87 tables in all, make up over half of each chapter. Chapters are devoted to the behavior of Grignard reagents with the following co-reactants: aldehydes, ketones, and ketenes (390 pages, including 270 pages of tables), quinones (19 pages), esters and lactones (159 pages, 113 pages of tables), carbonyl halides (57 pages of which 36 are tables), nitriles and cyano compounds (78 pages), carboxylic anhydrides (23 pages), carboxylic amides, imides, and lactams (38 pages), oxides of carbon and carboxylic acids (51 pages), epoxides (51 pages), ethers, acetals, and ketals (32 pages), alkyl halides (86 pages), "active" hydrogen compounds (32 pages), miscellaneous nitrogen compounds (64 pages), oxygen, sulfur, selenium, and tellurium (12 pages), sulfur, selenium, and tellurium compounds (28 pages), silicon compounds (25 pages), and miscellaneous non-metallic substances (13 pages). A chapter is also devoted to allylic rearrangements in the Grignard reaction.

The authors obviously have kept in mind the reference nature of the book. They have included helpful laboratory details—even liberal quotation of laboratory procedures from the literature—but they have also introduced interesting and provocative speculations, theories, and working hypotheses. One such example of interest is a proposed reaction scheme for the formation of the Grignard reagent.

The book is of unquestionable value particularly to organic chemists interested in the use of the Grignard reagent in syntheses. The book is a comprehensive, if not exhaustive, "ready reference compendium." To this end the authors have supplied a detailed table of contents, a general index, and a special Index of Grignard reagents. In addition the numerous tables are self-indexed by the empirical formulas of the co-reactants. It is stated that the literature covered up to the time of going to press; scattered references were found to articles for the year 1953.

Errors were detected in formulas, names, typography and spelling, but they are infrequent and are of minor importance when the scope of the subject matter is considered.

The printing and composition are good. The book is reproduced by an off-set printing which is pleasing and acceptable. In view of the already high cost of the volume, the selection of this economical but excellent method of reproduction is commendable. Although the price of the book precludes its purchase for many individual libraries, it will undoubtedly be an indispensable volume for all organic chemistry laboratories.

JAMES M. SPRAGUE

CURRENT TOPICS

"Giant Brains" for Aircraft.—Completely automatic flight and tactical operation of high-speed military aircraft and guided missiles is foreseen under a new working agreement reached recently by the Ramo-Wooldridge Corporation and Westinghouse.

In a joint statement issued by F. W. Godsey, manager of the Baltimore divisions of the Westinghouse Electric Corporation and Dr. Dean E. Wooldridge, president of the Ramo-Wooldridge Corporation, it was announced that under a $1,000,000 program Ramo-Wooldridge engineers and scientists will develop for use by the two companies airborne miniaturized versions of the so-called "giant brains" of business and industry.

Dr. Wooldridge and Mr. Godsey declared that "it is not commonly appreciated that recent advances in digital computing have been so rapid that it now appears practicable to design into lightweight airborne equipment much of the same high-speed, highly accurate computing and data-handling capability that characterizes the electronic equipment now being applied to scientific, business, and industrial tasks.

"This means taking today's bulky computers off the ground where they have been confined until now and converting them into compact and lightweight packages for aircraft, where they will automatically control simultaneous functions such as flight, navigation, engine and fire control in the higher-speed aircraft and guided missiles of the future."

The program is being financed by Westinghouse as part of its long-range development plans. It is anticipated that within two years sufficient progress will have been made to justify the use of this equipment in specific military aircraft.

Metal-Backed Nylon Bearings.—A new nylon-lined sleeve type bearing produced by the Nylacore Corporation of Great Neck, N. Y., has recently been placed on the market. The bearing is composed of a metal shell into which is molded an extremely thin lining or core of nylon of about 0.005-in. thickness rigidly anchored to the outer shell.

Very high precision is claimed for bearings of this type, with tolerances held as closely as plus or minus 0.0002 in. for bore, length, outside diameter and concentricity.

The very thin lining of nylon not only allows rapid dissipation of heat, but resists plastic deformation permitting a higher unit loading than is possible in other nylon bearings.

The bearings are made in several types, plain sleeve, with thrust collar, or with dust protector and oil seal as an integral part of the unit.

Due to the method of manufacture, sizes ranging from as small as $\frac{1}{32}$-in. diameter bore to large bearings are practical.

Radiation Gives Plastic Glasslike Qualities.—Polyethylene, which is made from oil-derived chemicals, now is on the market in dozens of useful products from squeeze bottles to garment bags. If experiments prove successful, it may soon be exposed to radiation which will give it new possibilities, some of them seemingly fantastic. Polyethylene plastic normally is white, waxlike, and easily melted. After a small dose of radiation, it will retain its strength and elasticity even at high temperatures. Further irradiation makes it stiff and glasslike. New possibilities may someday include unbreakable heat-resistant bottles or cellophane-like houses. The freedom of American industry to work out new products and possibilities brings home to Mr. and Mrs. America a host of beautiful new conveniences.

Navy Icebreaker Embarks for Antarctic Scientific Expedition.—The *USS Atka,* U. S. Navy icebreaker, embarked from Boston in December on a five month expedition to the Antarctic. The expedition, under the command of Commander Glen Jacobsen, will spend almost two months within Antarctic water engaged in studies preliminary to the International Geophysical Year (IGY), 1957–58, when 38 nations will carry out a world-wide research effort embracing such fields as meteorology, cosmic rays, solar activity, ionospheric physics, geomagnetism, oceanography, and glaciology. The U. S. Program of the IGY is to be carried out under the joint auspices of the National Academy of Sciences and the National Science Foundation.

An important mission of the *USS Atka* is to examine current icepack conditions and possible sites for the planned U. S. Antarctic effort during the International Geophysical Year in the Little America and other areas. In addition, scientific observations will be made during the voyage in meteorology, cosmic rays, oceanography, radio communications, and glaciology. The resulting information will greatly aid scientists in planning the details of the Geophysical Year program.

The U. S. Weather Bureau in conjunction with the U. S. Navy will conduct upper atmosphere soundings all along the route to and from the Antarctic, making two high altitude soundings every 24 hours, wherein upper winds, humidity, barometric pressure, and the temperatures will be obtained. This information will be useful in investigating research problems related to meteorology of the Southern Hemisphere.

It is also planned to investigate and examine the old meteorological station site at Little America to determine whether any of the equipment and buildings left there will be suitable for re-use.

Research on Muscular Dystrophy.—Failure of tiny chemical powerhouses between the cells of muscles may be the cause of crippling, frequently fatal muscular dystrophy, a University of Wisconsin medical scientist believes. Dr. John W. Harman, associate professor of pathology at the University of Wisconsin, places the blame for the disease on small, scarcely visible, bullet-shaped structures called mitochondria. Mitochondria, Dr. Harman explains, are little chemical furnaces which receive foodstuffs, convert them into energy, and then pass the energy on to meet muscle demand for fuel.

"It is suspected," Dr. Harman says, "that within these muscular powerhouses the derangement underlying the disease of muscular dystrophy may have its location." Just what that derangement is, Dr. Harman doesn't know. However, he can demonstrate that located within these microscopic furnaces are chemicals—the scientist calls them enzymes—which can wastefully bleed off the energy manufactured for muscle movement. And these same "suicide" enzymes are apparently associated with "structural collapse of the mitochondria and a subsequent collapse of the contractile unit."

(The "contractile unit" to which Dr. Harman refers is really the heart of muscle activity. It is a fine, strap-like thread—like a piece of elastic—which has the special capacity of shortening to a fraction of its original size. These threads, and there are billions of them in the muscle, are moored to the mitochondria by cables along which energy required by the muscle flows.)

But although Dr. Harman can show that the mitochondria have within them substances with which they can destroy themselves and the muscle cells they supply, he thinks that that answer is just too simple.

What he and his associates are doing is working toward a clearer understanding of a more complete picture: the integration of the food-to-energy process, the utilization of that energy and the units involved in the two processes—the mitochondria and the contractile units.

One of the big steps toward obtaining that total picture is a motion picture which Dr. Harman and his staff, along with Medical School Photographer Homer Montague, produced. The film, photographed through a high-powered microscope, shows many of these complex processes and the structures involved. The movie has been shown to several scientific bodies interested in muscular dystrophy, and, as Dr. Harman puts it: "Even we, who made the picture, learn something new every time we watch it."

A large part of Dr. Harman's research is being financed by a grant from the Muscular Dystrophy Associations of America, Inc.

Micro-Projector Features Unusual Simplicity of Operation.—Fast, simple projection of true-color microscope specimens for group study by doctors, students, and laboratory technicians is made possible by a new micro-projector announced recently by the Bausch & Lomb Optical Co., Rochester, N. Y.

The SpeedMatic Micro-Projector operates as simply as an ordinary slide projector without annoying distractions caused by lens changing, condenser focusing, or arc lamp adjustments, according to its designers.

Micro-projectors are valuable for hospitals, where many doctors, internes, and nurses can examine a problem specimen simultaneously, saving much time, money, and frequently, lives.

In schools, these instruments enable entire classes to study a specimen at the same time, eliminating the need for each individual to look through a microscope, thus saving considerable time and money.

Unique features of the compact SpeedMatic Micro-Projector which make possible its ease of operation include these:

1. A pre-aligned optical system mounts the four microscope objective lenses on a turret similar to that of motion picture cameras. The lens turret is geared to a similar rotor beneath the specimen table which contains the condensers needed to concentrate the illumination on each objective lens.

A flip of a lever brings a new lens into use, properly focused, while simultaneously the correct condenser is swung into position below the specimen table.

2. A new electronic system automatically maintains the correct spacing of the carbon electrodes in the arc illuminator. The light thus burns steadily with no flare or flicker, without need for manual adjustment of the carbons.

Uninterrupted viewing time with

the SpeedMatic is double that of conventional Micro-Projectors—an hour or more per set of carbons. Copper-coated carbons which conduct current efficiently permit the much longer burning time.

3. The SpeedMatic projects true-color images because it has no water cell heat barrier to tint the illumination. Specimens are protected from the arc lamp heat with a new type of heat absorbing glass. For super-sensitive specimens that may be encountered, an additional water-cell cooling accessory is available.

Other features include a practical range of magnification from 30 × to 3000 × at a projection distance of 12 ft. The horizontal specimen table permits samples in liquid to be examined.

Specimen slides are mechanically positioned beneath the lens without jerky trial-and-error. All optical elements in the system are Balcoted (covered with a thin hard film that cuts down glare), producing maximum efficiency of the illuminating system. The unit is light, highly portable, and easily assembled.

New Laboratory Electromagnet.—A new laboratory electromagnet embodying the most convenient features for varying magnetic field configurations was announced recently by Varian Associates, Palo Alto, Calif., manufacturers of klystron tubes and n-m-r spectrometers.

Varian's new magnet, the V-4004, has two fixed energizing coils with adjustable poles and readily changeable pole caps. A wide range of field contours can be set with ease. By a simple adjustment of each pole, any air gap width up to 4.3 in. can be achieved. A variety of cylindrical, conical or specially-shaped pole caps are available for wide choice of flux patterns. Despite the comparatively small size of this new magnet, a gap field flux density as high as 28,600 gauss can be attained.

According to Varian Associates, no other laboratory magnet of comparable size can match the V-4004's high fields and over-all mechanical versatility. They envision widespread applications for general laboratory needs where the experimental conditions require precise magnetic field.

"Lost" Planet "Found" by Electronic Brain.—"Lost" planets are having a tough time staying that way when astronomers combine a telescope and the "electronic brain" to locate them. This time-saving combination was employed recently when Dr. Paul Herget, Director of the Cincinnati Observatory, rediscovered the planet, Athalia, lost for 50 years, by using the General Electric Company's giant IBM 701 computer to figure its orbit.

The planet, originally discovered photographically at the Heidelberg Observatory in Germany on Sept. 20, 1903, was observed again on Sept. 29, Oct. 13 and 19. It was given the number 515 and the name Athalia. The orbit was computed for this planet from the observations in the usual manner, but the planet was not photographed again until 1948 when Indiana University took about 2000 plates of minor planets.

While checking these plates recently to determine the orbits of the planets, Dr. Herget solved the astronomical problems on the 701 computer which G.E.'s Aircraft Gas Turbine Division here normally uses for research and engineering purposes.

By using the machine, it was possible to calculate the planet's orbit in just one minute compared to weeks of hard work with a desk calculator.

The orbit path shown by the "electronic brain" revealed that the recent

Indiana observations could be brought into full agreement with the old observations of Athalia at Heidelberg in 1903.

Dr. Herbert R. J. Grosch, who manages the analytical and computing services at the General Electric Company's Aircraft Gas Turbine Division plant in Cincinnati, recalls that when he "rediscovered" Jupiter's eighth satellite in 1941 while working on his doctor's degree at the University of Michigan, it took him over 1000 man-hours of work to get the same calculations which he could now obtain in just one minute by using the "electronic brain."

Fibreglass Helmets.—Air Force pilots and other crew members of jet-fighters and bombers soon will begin wearing fibreglass helmets as standard flight equipment. The decision to change from cotton duck helmets to fibreglass came as a result of development of a light-weight fibreglass helmet by ARDC's Wright Air Development Center, near Dayton, Ohio, working in conjunction with industry. The new helmets will replace the cotton duck head gear as the latter become unserviceable. More extensive rigidity tests are to be made on the cotton duck helmets still considered serviceable and those that show defects also will be replaced with the new helmet.

Until now the Air Force had not adopted the fibreglass helmet because it was impossible to obtain one with the same weight and resistance qualities of cotton duck. The Air Force requires that its helmets withstand an impact of 64 ft.-lb., equivalent to an 8-lb. spherical weight free-falling from 8-ft., and that the helmet show no penetration when a 1-lb. plumb bob is dropped from 10 ft.

This impact strength was attainable, but the weight was too great. Small helmets, the Air Force insists, must weigh no more than 17 oz., with weights up to 20 oz. for the large sizes. The newly-developed item meets both strength and weight specifications.

The fibreglass helmet has a number of advantages over the old-type headgear. The latter is constructed of cotton duck treated with phenolic resin and has extra layers of cloth on the top and edges, where extra strength is required. This usually resulted in projections inside the helmet, whereas fibreglass helmets, constructed of preformed short fibres, give a uniform shape.

When molded, the cotton duck laminate produces so much warping that no two helmets are exactly alike. This makes it extremely difficult to fit helmet accessories, such as binoculars, visors, oxygen masks, etc., to the helmets. With the fibreglass helmet, the accessories can be made to exact measurements with the knowledge that they will do an effective job.

In addition to these advantages, the fibreglass helmet is unaffected by heat, cold or age. Cotton duck, on the other hand, becomes soft at 160 to 180° F., becomes brittle at $-20°$ F. and also becomes brittle with age.

Wind Silencers for Your Car.—American Homecraft Co., Chicago, has introduced a wind silencer to quiet the roar of the wind in a moving automobile. Designed by aeronautical engineers, Wind Silencers reduce wind-roar and noise to a gentle whisper, so that occupants of the car can listen to the car radio in living room comfort, and converse with ease at any speed. Wind Silencers are made of strong, good looking stainless steel and are extremely simple to install on any car.